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A LABORATORY GUIDE FOR A COURSE IN GENERAL BOTANY

By R. M. HOLMAN AND W. W. ROBBINS

A Textbook of General Botany.

For Colleges and Universities. By Richard M. Holman, Assistant Professor of Botany in the College of Letters and Sciences of the University of California; and Wilfred W. Robbins, Associate Professor of Botany in the College of Agriculture of the University of California. ix+590 pages. 6 by 9. 374 figures. Cloth, $4.00 net.

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BY

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AND
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PREFACE

THIS Guide had its origin in mimeographed directions for laboratory work, prepared five years ago and considerably revised and reprinted each year. Two of the authors have worked together for these five years, and the third for three years, over the problems of organizing and teaching large classes in General Botany. On the basis of their experience at the University of California and elsewhere, they feel convinced that in many courses in elementary botany the number of structures, types, and topics presented is much too great for the student to assimilate properly. Very much more important than covering a great many subjects is a thorough study and fairly complete understanding of a few. Furthermore, when a great variety of subjects are taken up in the laboratory, the student is likely to be hurried through a long series of set tasks without having an opportunity to realize what the object of most of them is. On that account, the authors have not attempted to introduce any laboratory work in Ecology, Genetics, or several other phases which might well be introduced if time were available to take up these subjects after a thorough and rather intensive study of the fundamentals of morphology and physiology.

These laboratory directions are designed for a year's course of two periods weekly (each of two and one-half or three hours), but there should be no difficulty in so choosing exercises that the Guide may be used for a briefer course. There is no reason why the different divisions of the work should not be taken up in some other order than that in which they are presented here. When a change in the order results in the student's encountering unfamiliar terms which have been defined or explained in earlier pages of the book, the glossary will furnish the needed definitions.

It is quite generally recognized by teachers that, in the case of large elementary college classes of a hundred or more students, the study of the physiology of plants by means of experiments

carried on by the students themselves, is practically out of the question, unless large expenditures for duplicate equipment are made, specially equipped laboratories provided, and, what is most difficult of all, a considerable number of assistants, specially trained for such work, are available. On this account, the physiological exercises have been written in the form of directions for the observation of demonstrations; but these may be readily adapted by the teacher so that they will serve as directions for experiments by the students, if conditions favor the work being given in this way.

In the course at the University of California, several of the physiological exercises and one or two of the types in Part II have been omitted during the past few years.

In the Appendix, near the end of the book, the teacher will find a number of notes on collection, culture, and use of material, and on the conduct of the laboratory work. To avoid confusing the student, no references to these notes have been made in the text. These items have been arranged under the same headings as the laboratory directions, and it is suggested that the teacher refer to the notes on each group of exercises before those exercises are taken up in the laboratory.

The authors believe that, whenever possible, living material should be used for study, and that the student should cut his own sections and make his own preparations. Very satisfactory sections can be made by the student with a safety razor blade, after a little practice. Sectioning with a razor blade is easier for some when a razor blade holder is used. Several convenient forms of razor blade holders are now on the market.

In some cases it is impossible to avoid the use of stained and permanently mounted preparations. When these are used, it is desirable that living material of the plant in question be available in the laboratory for examination by the student and that the student make and examine rough preparations of this material before studying the slides. The prepared slides sold by the Biological Supply Companies are often unsatisfactory, but one of the best of these companies has made, according to our instructions, a set of all the slides called for in this manual. The company's address is given in the Appendix on page 85.

The authors believe, as mentioned above, that training in careful and precise observation, thinking and expression, and a

clear understanding of the fundamentals of plant structure, development, and functions are the most important ends to be sought in a course of this sort. On that account they favor a rather intensive study of a few plants instead of a more superficial survey of many forms. At the same time, they realize that it is possible for a student to study quite intensively a single fern or conifer, or flowering plant, and yet know very little about ferns as a group or about conifers or flowering plants as a group. They have therefore introduced into the course some exercises on the determination, by means of keys, of some of the commoner ferns, conifers, and angiosperms.

SEPTEMBER, 1925.

LEE BONAR.
RICHARD M. HOLMAN.
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TO THE STUDENT

In the laboratory the student will be expected to examine closely the material furnished for study in order to make out all the details of structure that can be seen by the naked eye, or in other cases by the use of the dissecting microscope or the compound microscope. The habit of close scrutiny of natural objects is essential for any person who is entering upon scientific study. Such careful examination, even without the microscope, will often reveal, even in the case of plant parts with which the student may believe himself thoroughly familiar, structures, the existence of which he has never suspected.

As an aid in this searching examination of the material and as a proof that the parts present have been seen, the student will be required to draw many plant structures studied in the laboratory. The drawing is not an end in itself. Mere talent in drawing will in no case be made the basis for credit, but each student will be expected to do this work to the best of his ability. Not infrequently, students with natural ability in drawing do less satisfactory work, on account of failure to make out important details, than others who are without natural ability or training in drawing and who may even doubt, at the beginning, their ability to represent the objects studied. Satisfactory drawings can be made by practically any student who makes a reasonable effort.

Scientific Names of Plants

Although common names of plants are useful and largely employed in applied botany, they can not take the place of scientific names, for a single plant may have many different common names in one locality and the common name of a plant often varies in different localities. Furthermore, several species, often not closely related, may have the same common name. For these reasons the scientific name is employed not only in pure botany,

but in applied botany (forestry, horticulture, agronomy, etc.), when any but the most generally known species are referred to. The scientific name consists of two parts, the **generic** name, or **genus** name, and the **specific,** or **species** name. **The generic name always begins with a capital.** Several kinds of plants (species) may belong to a single genus. Thus *Pinus* is the genus of the pines, of which there are many species, as *Pinus ponderosa* (yellow pine), *Pinus radiata* (Monterey pine), etc. So also *Triticum* is the genus of wheat, but included in this genus are *Triticum polonicum* (Polish wheat), *Triticum dicoccum* (emmer), *Triticum vulgare* (common wheat), *Triticum durum* (durum wheat), and others. Just as a number of closely related species make a genus, so several closely related genera make a family, several families an order, several orders a class, and several classes a division.

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BOOKS FOR REFERENCE AND COLLATERAL READING

General Texts—

Holman and Robbins—Textbook of General Botany. Wiley and Sons, New York, 1924.

Fitting, Jost, Schenck and Karsten—Strasburger's Textbook of Botany, 5th English Edition. Macmillan & Co., London, 1921.

Bower—The Botany of the Living Plant, 2nd Edition. Macmillan, London, 1923.

Ganong—A Textbook of Botany. The Macmillan Company, New York, 1918.

Coulter, Barnes & Cowles—Textbook of Botany, Vol. 1. American Book Company, New York, 1910.

External Morphology of Seed-Bearing Plants—

Gray—The Elements of Botany. American Book Company, New York, 1887.

Plant Anatomy—

Stevens—Plant Anatomy, 4th Edition. P. Blakiston's Son & Company, Philadelphia.

Haberlandt — Physiological Plant Anatomy. Macmillan, London, 1914.

Plant Cytology—

Sharp—An Introduction to Cytology. McGraw-Hill Company, New York, 1921.

Plant Physiology—

Palladin—Plant Physiology, 2nd American Edition. Translated and edited by Livingston. P. Blakiston's Son & Company, Philadelphia, 1923.

Jost—Lectures on Plant Physiology, Translated by Gibson. Clarendon Press, Oxford, 1907.

Chemistry of Plants and Plant Products—

Onslow—Plant Biochemistry. Cambridge University Press, 1920.

Haas and Hill—The Chemistry of Plant Products, 3rd Edition. Longmans, Green and Co., London, 1921.

The Plant and the Soil—

Russell—Soil Conditions and Plant Growth. Longmans, Green, London, 1921.

The Algae—

West—Algae, Vol. 1. Cambridge University Press, 1916.

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Stevens—Diseases of Economic Plants. The Macmillan Company, New York, 1921.

Mosses, Liverworts and Ferns—

Campbell—Mosses and Ferns, 3rd Edition. Macmillan, New York, 1918.

Morphology of the Reproductive Structures of Seed-Bearing Plants—

Coulter and Chamberlain—Morphology of Gymnosperms. Revised Edition. University of Chicago Press, 1917.

Coulter and Chamberlain—Morphology of Angiosperms. D. Appleton & Co., New York, 1903.

The Botany of Economic Plants—

Robbins—Botany of Crop Plants, 2nd Edition. P. Blakiston's Son & Company, Philadelphia, 1924.

Systematic Botany of the Seed-Bearing Plants—

For the Northeastern and Central States

Gray—A Handbook of the Flowering Plants and Ferns, 7th Edition. American Book Company, New York, 1908.

Britton—Manual of the Flora of the Northern States and Canada. Henry Holt and Company, New York, 1905.

For the Southeastern States

Small—Flora of the Southeastern United States. The Author, New York, 1913.

For the Rocky Mountain Region

Coulter—New Manual of the Botany of the Central Rocky Mountains. Revised by Nelson. American Book Company, New York, 1909.

For the Pacific Coast

Jepson—A Flora of the Economic Plants of California. Associated Students Store, University of California, 1924.

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Sudworth—Forest Trees of the Pacific Slope. U. S. Department of Agriculture, Forest Service, Washington, 1908.

Abrams—Flora of Los Angeles and Vicinity. Stanford Book Store, Stanford University, 1917.

Frye and Rigg—Elementary Flora of the Northwest. American Book Company, New York, 1914.

Piper and Beattie—Flora of the Northwest Coast. New Era Printing Company. Lancaster, Pa., 1915.

History of Botany—

Gibson—Outline of the History of Botany. A. and C. Black, London, 1919.

Evolution and Heredity—

Darwin—On the Origin of Species. Various publishers.

Morgan—A Critique of the Theory of Evolution. Princeton University Press, 1916.

Coulter, M. C.—Outline of Genetics. University of Chicago Press, 1923.

Babcock and Clausen—Genetics in Relation to Agriculture. McGraw-Hill Company, New York, 1918.

A LABORATORY GUIDE FOR A COURSE IN GENERAL BOTANY

Part I

THE PLANT CELL

All plants are made up of structural units called cells, and all the activities of plants are directly dependent on the activities of some of these structural units. On that account we shall first study the structure and some of the activities of plant cells. This will be followed by an examination of the principal kinds of tissues (groups of similar cells adapted to a given function) found in plants, so that in the subsequent study of the different organs of the plant, the tissues of which they are constructed may be recognized. After the relation of the various organs of the plant have been briefly studied under the heading, "The Plant as a Whole," the different organs of the seed-bearing plant will be taken up in succession.

Reading Assignment:

Holman and Robbins, pp. 13–39.
Stevens, Plant Anatomy, Chapter I.

Material for Study:

1. Stem tips of pumpkin (*Cucurbita pepo*), squash (*Cucurbita maxima*), or almost any other member of the squash family (Cucurbitaceae).
2. Scales from the bulb of onion (*Allium*).
3. Shoots of *Elodea*, an aquatic seed plant.
4. Fruits of red bell pepper (*Capsicum annuum*), tomato (*Lycopersicum esculentum*), and carrot (*Daucus carota*); the petals of some yellow flowers or of pansy (*Viola tricolor*).

5. Leaves of the striped-leaf wandering Jew (*Zebrina pendula*), or leaves of *Iresine Lindeni* or other species of that genus.
6. Stained and permanently mounted longitudinal sections of the root tip of onion (*Allium*), showing nuclei in division.

DIRECTIONS FOR WORK:

1. With your razor blade, cut from near the extreme tip of a squash or pumpkin stem several rather thin cross sections. Mount in water on a slide and cover with a cover glass. Examine these sections with the low power of the compound microscope and study the form and structure of the two types of hairs (**pointed** and **capitate**).

Draw a large, uninjured, and typical pointed hair as seen with the low power, but on a large scale (not shorter than 4 inches).

All the details visible with the low power should be accurately shown. Note that changes in the illumination, affected by moving the mirror or adjusting the iris diaphragm, often bring out details of structure more clearly.

Find a large cell that shows clearly all the cell structures and the streaming of the cytoplasm. **Draw** this cell on a large scale as seen with h. p.* Indicate the movement of the cytoplasm by arrows. The cytoplasm can be best represented by stippling (numerous small, equally spaced dots).

2. Strip a piece of the epidermis from the inner surface of an onion scale and mount in water. Examine the cells with the low and with the high power. Note whether any of the structures seen in the squash or pumpkin hair are lacking from these cells, and study the streaming of the cytoplasm, which can best be seen near the ends of the cells. **Draw** a single cell on a large scale.

3. Remove several of the younger leaves from a shoot of *Elodea*. Mount, and examine with l. p. and h. p. Look for the structures seen in the cells of the hairs of the squash or pumpkin. What structures are you unable to locate? Note the difference between the views secured when the microscope is focused on the upper or lower surface of the cell (surface view) and when it is focused halfway between the two surfaces (median optical section). **Draw** two diagrams showing a cell as seen in these two views. In these diagrams the number and forms of the green bodies

* From this point on, the low power of the compound microscope will be indicated by the letters "l. p.", the high power by "h. p."

(**chloroplasts**) should be accurately shown. In at least one of these diagrams, indicate the course of the streaming cytoplasm by means of small arrows. Find chloroplasts which appear to be dividing. **Draw** such a chloroplast on a large scale.

4. Cut a thin section through the flesh of the tomato or pepper fruit at right angles to the surface, mount, and study with l. p. and h. p. **Draw** on a large scale at least two cells showing all the structures in the cells and particularly the orange-colored **chromoplasts.** The latter structures soon undergo change of form when placed in water. On that account, the drawings should be made from material recently mounted. **Draw** also several chromoplasts on a much larger scale.

5. Clean two slides. On one place a large drop of water and on the other a drop of the 20 per cent cane sugar solution which will be found in a dropping bottle on the laboratory table. Strip pieces of the colored epidermis from the lower side of a leaf of *Zebrina* or *Iresine.* Mount several pieces, surface side up, on each of the slides. Cover with cover glasses and examine at three-minute intervals until a marked change, most clearly visible in the colored cells, has taken place in some of the colored cells of one of the preparations. Then **draw** two or three of the altered cells and a like number from the other preparation. Explain the reasons for the change observed (**plasmolysis**). Remove the cover glass from the preparation mounted in sugar, wipe off most of the solution and replace it with water. Then cover with a cover glass and examine from time to time under the microscope to see if the altered cells regain their original condition.

6. With l. p. examine the stained sections of onion root tip which are furnished you. Note the form of the cells in different parts of the sections and the length of the cells as compared with the width. Observe also whether the cells near the pointed end or those farther back have the denser cell contents. Among the small cells near the pointed end, find and study with h. p. one that shows clearly the **cytoplasm**; and the **nucleus** with its membrane, **nucleoli** (singular **nucleolus**), **chromatin granules**, and fine **net-work** of **linin.** Nuclei showing all these structures are said to be in the resting condition. Make a large-scale **drawing** of a cell with resting nucleus.

Some of the cells in the region of the extreme tip will be found to have nuclei which are undergoing nuclear division, or **mitosis.**

The instructor will explain this process if it has not already been discussed in the lectures. **Draw** diagrams of at least four different stages in the process of mitosis as seen under the demonstration microscopes set up by the instructor.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Distinction Between Pure Substances, True Solutions, Colloidal Solutions and Heterogeneous Mixtures

a. Pure substances are of two kinds, **elements** and **compounds.** Familiar examples of elements are sulphur, mercury (quicksilver) and aluminum. More than eighty such elements are known; from these, all other substances are made up. An element can not be changed into any other substance except by adding another element or elements to it and thus forming a compound.

A compound always consists of two or more elements united in certain definite and constant proportions. Familiar examples of compounds are water, common salt, and carbon dioxide. Water is a compound of the two elements, hydrogen and oxygen, in the proportion, by volume, of 2 to 1. Common salt is a compound of the elements, sodium and chlorine, in the proportions, by weight, of about 23 to 35.5. The smallest quantity, or unit, of a compound, is called a **molecule,** and the particles of elements which unite to form molecules of a compound are called **atoms.** Several atoms of a element can also combine to form a molecule of an element. Thus, oxygen gas is made up of oxygen molecules, each consisting of two oxygen atoms. Briefly, then, a pure substance is a substance the molecules of which are of one kind only. If more than one kind of atom is present in a pure substance, the substance is a compound; if only one kind, the substance is an element.

b. A quantity of matter in which more than one kind of molecule is present is spoken of as a **mixture;** that is to say, any material consisting of two or more pure substances not united into a compound is a mixture. The elements in a compound are always present in certain definite and constant proportions, but a mixture may vary greatly as to the proportions of its constituents. Mixtures are of two principal kinds: **true solutions** and **heterogeneous** mixtures. If a small quantity of the pure substance, salt, is added to the pure substance, water, and the container

is shaken or its contents stirred, the salt disappears. As the salt goes into solution in the water, the salt molecules become separated from one another and uniformly distributed through the water. The largest particles in such a true solution are molecules; and, since molecules are too small to be seen by even the highest powers of the microscope, the different constituents of a true solution can not be distinguished by the eye.

A true solution differs from a compound in two respects: first, in that it consists of at least two kinds of molecules; and second, in that the proportions of the components may vary. Thus, salt solutions may contain any concentration of salt from only a trace to thirty parts or more of salt to one hundred of water. Solutions are generally liquid, but there are also gaseous solutions (air) and solid solutions.

If the particles of one or more of the substances in a mixture are larger than molecules, the mixture is a **heterogeneous mixture.** A piece of granite is a heterogeneous mixture consisting of particles of different kinds of rock, clearly visible to the eye. Similarly, a mixture of white sand and sugar is a heterogeneous mixture. The particles can be readily distinguished by the use of a lens or a microscope, and are many times larger than molecules.

A particular kind of heterogeneous mixture which is of great interest, especially to botanists and zoologists, is the **colloidal solution.** In most colloidal solutions one or more of the components is mixed with a liquid, and is in so fine a state of division (either as tiny solid particles or as droplets) that it does not tend to settle out, or at least settles out very slowly. The suspended particles of a colloidal solution may be too small to be seen by the most powerful microscopes, but are larger than molecules. In such cases a colloidal solution may appear perfectly clear, like a true solution. If an intense beam of light is passed through a colloidal solution, however, the path of the beam will be distinctly visible where it passes through the solution because the colloidal particles in suspension are large enough to reflect the light. If a true solution (for example, salt in distilled water) is used, the path of the light through the solution will not be visible, because the particles in suspension are not large enough to reflect the light.

c. Something of the significance of the subjects just discussed,

in connection with the plant cell, will be made clear by the following statements in which the terms defined above are used:

The protoplast of a plant cell is generally surrounded by a wall composed of the **compound,** cellulose, the **molecules** of which are made up of **atoms** of the **elements** carbon, hydrogen and oxygen. Everything that enters the plant cell, must be in the form of a true solution for substances in **colloidal solution** can not pass through the wall or the cytoplasmic membrane of the protoplast. The cytoplasm itself is a **colloidal solution** in which very small particles of proteins and other substances are suspended in a watery **true solution.** The liquid filling the vacuoles is a **true solution** of many substances, including certain gases, dissolved in water. The cytoplasmic membrane prevents or greatly restricts the movement of certain molecules into or out of the cell, even though they are in **true solution.**

2. Diffusion

There will be set up in the laboratory a water-filled glass cylinder or tube at the bottom of which has been placed a piece of copper sulphate or other soluble colored substance. The vessel should not be touched or jarred. Observe from day to day, and note how long a time passes before the liquid becomes equally colored throughout. What does a difference in intensity of the color indicate as to the distribution of the particles of the dissolved substance? What keeps the dissolved particles of a substance, which is heavier than water, in suspension after it has dissolved?

3. Osmosis and Osmotic Pressure

Observe the apparatus (osmoscope) set up in the laboratory to demonstrate that when a solution is separated from water or from a less concentrated solution of the same components by a membrane through which the dissolved substance can not pass, or passes very slowly, a pressure arises. Explain why the volume of the solution within the osmoscope increases, and state what evidence there is of pressure within the osmoscope. Make a diagram of the apparatus and explain fully. Compare the apparatus to a living cell immersed in water.

4. Relative Diffusibility of Substances in True and Colloidal Solution

A dialyzer (a sac of parchment paper or collodion), containing a diluted starch paste to which some common salt has been added, is placed in a beaker of distilled water. Care should be taken that none of the contents of the dialyzer is spilled into the water. After several hours, one portion of the water will be tested for starch by adding some iodine solution, which gives a blue color in the presence of starch; and another portion for common salt, by adding a little silver nitrate solution, which will give a white precipitate if salt is present. Which, if either, of the two substances (starch or salt) diffused through the membrane? What circumstance determines which substance, if either, is retained and which passes through?

5. Effect of Turgor on Length and Rigidity of Tissue

By means of a cork borer cylinders about 8–10 millimeters in diameter and 6–10 centimeters in length are cut from potato tubers, and trimmed to exactly the same length. Some of them are placed in pure water, others in a very concentrated salt solution, and still others are boiled for five minutes. Compare the length and rigidity of the cylinders after half an hour, and account for the differences, if any are observed. This demonstration (or experiment) can also be performed with rhubarb or the fleshy peduncle of such flowers are *Richardia* (calla) or *Amaryllis*. If either of these plants is available the demonstrations (or experiment) should be repeated with it. Endeavor to explain any difference between the results obtained and those observed in the case of the potato tissue.

6. Demonstration of Effect of Death on the Permeability of the Cytoplasmic Membrane

Examine the microscopic demonstration of sections of red beet. Determine whether the red color is present in chromoplasts or is dissolved in the cell sap. Compare two test tubes containing thin slices of red beet which, after being washed, have been placed in pure water. The slices in one tube have been boiled. Explain any difference in the appearance of the two preparations.

7. Respiration

There is constantly taking place in the living cells of all plants and animals a process called respiration, by which complex substances in the cell, such as grape sugar ($C_6H_{12}O_6$), are broken down into simple compounds such as carbon dioxide (CO_2) and water (H_2O).

In most cases the plant or animal is unable to carry on this process unless it can absorb oxygen, for oxygen is necessary to ordinary respiration just as it is to the somewhat similar process of combustion, or burning. Respiration involves the destruction of useful substances. It is, nevertheless, essential to the life of the cell, and therefore of the whole plant or animal, for it furnishes energy which is necessary for various processes that must go on in the cells.

Observe, and report fully in writing, the following demonstrations:

I. *To show that baryta water (solution of barium hydroxide) or lime water (solution of calcium hydroxide) when in contact with carbon dioxide gas forms a white precipitate:* A stream of carbon dioxide from a cylinder of the gas is permitted to bubble through a quantity of clear baryta water or lime water.

II. *To show that the atmosphere contains carbon dioxide:* A quantity of lime water or baryta water is exposed to the air in a shallow vessel.

III. *To show that air may be deprived of carbon dioxide by being passed through a solution of caustic potash (potassium hydroxide):* Air is caused (*a*) to bubble through water and then through barium hydroxide solution (baryta water), and (*b*) to bubble through a solution of caustic potash and then through barium hydroxide solution.

IV. *To show that carbon dioxide (a product of respiration) is present in considerable quantity in the air exhaled from the lungs:* The demonstrator blows his breath into clear lime water or baryta water through a tube.

V. *To show that carbon dioxide is given out by plant tissue:* The apparatus consists of a series of five bottles or flasks, so connected by rubber stoppers and tubing that a stream of air can be drawn through the whole series without any of the liquid contained in the first, second, fourth, or fifth containers leaving these vessels.

The five vessels contain respectively: (1) caustic potash solution, (2) baryta water, (3) leaves, germinating seeds or other living plant tissue, (4) baryta water, and (5) caustic potash solution. Air is drawn through this series of vessels by means of a filter pump or aspirator. In describing this demonstration the student should not fail to explain why each of the four solutions is used, and should also make a neat diagram of the apparatus.

VI. *To show that when respiration is prevented by depriving the plant of oxygen, normal growth and development are interfered with:* Two lots of soaked seeds are placed in enclosed chambers, the plant of oxygen, normal growth and development are interfered with: Two lots of soaked seeds are placed in enclosed chambers, *A* and *B*, from one of which (*B*) all oxygen has been removed by means of an oxygen-absorbing solution (potassium pyrogallate). The seeds are left in these chambers in the dark (Why?) for several days and then observed. A neat diagram of the apparatus should accompany the account of this demonstration.

Questions

Before passing on to the next exercise, the student should answer the following questions:

What is a cell? Name the parts of a typical green plant cell. How does a typical plant cell differ from a typical animal cell? What is a protoplast? Protoplasm? Cytoplasm? Name the parts of the nucleus. What do the vacuoles of plant cells contain? Of what material is the cell wall composed? Which of the following are dead, which living: nucleus, cell wall, vacuoles, cell sap, cytoplasm, plastids? What is a chromoplast? Of what use to a plant may the pigments in its cells be? Explain, as fully as you can, what happens when a living cell is placed in a concentrated solution of sugar. Does the process necessarily kill the cell? What happens if the cell is placed in water again after a little while? What structures in the cell bear the hereditary characters? In what condition of the cell are these structures most easily seen?

What is meant by a semi-permeable membrane? Explain wilting. State a number of ways in which it may be caused. Can a wilted plant recover its normal condition? How? Explain what is meant by turgor. How is the number of cells of a plant increased? Give an account of the changes which the nucleus

undergoes during cell division. Contrast the processes of photosynthesis and respiration. Which process, if either, is restricted to animals? Why? Which, if either, to plants? Why? Is either process restricted to certain kinds of plant cells? If so, to what cells and why?

PLANT TISSUES

In the simplest of plants, such as the Bacteria and certain of the Algae, the whole plant body consists of a single cell which is capable of performing, and does in fact perform, all the vital functions. In other simple plants the plant body consists of a small group of cells which are practically all alike. In many such plants every cell carries on all of the processes necessary to life. In most plants, however, there are thousands of cells and these are of different kinds according to the functions which the different groups perform for the whole plant. The cells differ in many ways, i.e., length, width, thickness of cell wall, presence or absence of spaces between them (intercellular spaces), presence of thin places (pits) in the cell walls, chemical nature of the cell walls, etc. A group of similar cells having a common origin and a common function is called a tissue.

Reading Assignment:

Holman and Robbins, pp. 42–48.
Stevens, Chapters IV and V.

Material for Study:

1. Leaves of dock (*Rumex*). Stem of tomato (*Lycopersicum*).
2. Shoots of wandering Jew (*Tradescantia sp.*).
3. Leaves of New Zealand flax (*Phormium tenax*). *Linum* or other plant having abundant and typical bast fibers.
4. Stained cross and longitudinal sections of Dutchman's pipe (*Aristolochia*), *Platanus*, apple, or other woody stem.
5. Stained cross, tangential and radial sections of the wood of pine (*Pinus*).

Directions for Work:

1. With a razor blade, make thin sections of the petiole (leaf stalk) of *Rumex*, or of the stem of tomato. Mount in water

under a cover glass and with the l. p. find, near the edge of a section, a group of cells which have their walls greatly thickened at the corners. Using h. p., examine this tissue (**collenchyma**) more carefully. With proper illumination, the middle lamella can be clearly made out at the corners. By "middle lamella" is meant the original dividing wall formed before thickening began. **Draw** three or four of these cells with a portion of those adjoining them. The shortest diameter of the individual cells in this drawing should not be less than $\frac{3}{8}$ inch. Examine the large thin-walled cells, with numerous intercellular spaces, in the center of the section. **Draw** several of these, including one containing a spherical mass of crystals.

2. Make a number of thin sections of the stem of *Tradescantia* and examine the thin-walled tissue in the center of the section. Note its resemblance to the tissue found in the same region in the *Rumex* petiole. This thin-walled tissue, with conspicuous intercellular spaces and with long-lived protoplasts within the nearly isodiametric (all diameters about the same) cells, is called **parenchyma.** **Draw** several cells on a large scale (h. p.) and show the nucleus and any other structures which may be seen within the cells. The cell wall should be represented by two lines, but these must be near together and fine. **Draw** also on a large scale (h. p.) several of the needle-shaped crystals (**raphides**) which will be found floating free in the preparation. These are normally contained in special elongated parenchyma cells, some of which were ruptured when sections were made.

3. Make thin cross and longitudinal sections of the base of the leaf of New Zealand flax, and mount in water after teasing the longitudinal sections apart with the needles in order that the individual fibers, of which the tissue is largely composed, may be distinguished. Examine the bast fibers with l. p. and h. p. in both cross and longitudinal section, and **draw** three or four on a large scale (h. p.) and in both views, making the diameter of each fiber not less than $\frac{1}{4}$ inch. Split off a long piece of the leaf $\frac{1}{8}$ to $\frac{1}{4}$ inch wide and try to break it. It is to the bast fibers that flax, hemp, and most other cordage plants owe the properties that make them so valuable for cordage purposes.

4. Examine the cross and longitudinal sections of dicotyledonous wood furnished you, and locate, with both h. p. and l. p. the following:

a. **Epidermal hairs.**

b. **Epidermis** (surface tissue) with thickened outer wall.

c. **Collenchyma,** several layers of cells just below the epidermis.

d. **Parenchyma,** just below the collenchyma and in the center of the section.

e. **Bast fibers,** angular, thick-walled cells.

f. **Phloem.** Just outside the cambium, opposite the wood. Note the "sieve plates" present in many of the "sieve tubes" of the phloem.

g. **Cambium,** small, rectangular cells in definite rows just outside the wood.

h. **Wood,** large tracheal tubes or water ducts and other elements in wedge-shaped masses, just outside the pith.

i. **Cork,** thin-walled cells on the outside of the oldest section.

With l. p., locate in the longitudinal section all of the tissues listed above except epidermal hairs, epidermis, and collenchyma.

Draw, as seen with h. p. in both cross and longitudinal sections and on a large scale, a few cells of the cork, bast fibers, and wood.

Draw, as seen with the h. p. in cross section, several cells of the collenchyma, epidermis, and cambium.

The cambium shares with the cells of the root tip, such as we studied in the exercise upon the cell, and with certain cells within the buds, the ability to give rise, by repeated divisions of its cells, to other tissues. All tissues which can give rise continuously to other tissues are called **meristems,** or **meristematic tissues.**

5. Cut thin shavings from the sides and the end of a match, mount these in water, and examine them with l. p. and h. p. Then compare with the stained, mounted sections of pine. Study the latter and identify, in all the sections, the following: **tracheids, summer wood, spring wood, annual rings, bordered pits, resin ducts, medullary rays.** Be sure that you can explain the structure of the wood of pine in detail when called upon to do so. **Draw** a considerable portion of the cross section, the radial section, and the tangential section on a small scale as seen with l. p. **Draw,** also on a very large scale, from twenty to thirty cells from each section, including a medullary ray, and, in the cross and radial section drawings, an annual ring with some spring wood and some summer wood. In the cross-section drawing, show a resin duct.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Effectiveness of Epidermis in Reducing Water Loss

Two apples, of approximately the same size and free from blemishes, should be accurately weighed after the skin (epidermis) has been removed from one. They should then be suspended from strings in the laboratory and again weighed, at intervals of one or two days, for a week or ten days. Compare the rate of loss in weight (due mostly to evaporation of water). Examine a cross section through an apple peel and **draw** several epidermal cells showing the form of the cells and the thickness of the cuticle.

2. Effectiveness of Cork in Reducing Water Loss

Two potatoes of approximately the same form and size should be treated in the same way as were the apples in 1. and a record made, as in the preceding case, of the rate of loss in weight of the peeled and unpeeled tubers. Make sections of potato peel, examine with h. p., and show by **drawings,** the character of the six or eight outermost layers of cells.

Questions

What is cutin? Suberin? Lignin? Characterize the following tissues as regards: (1) relation between length and width of the cells, (2) thickness of cell wall, (3) presence of thinner or thicker areas in the cell wall, (4) presence of other substances than cellulose in the cell wall, (5) length of life of the protoplast, (6) functions: parenchyma, bast fibers, ordinary epidermal cells, cambium, collenchyma, tracheids, sieve tubes, and tracheal tubes. Why are bast fibers valuable in making cordage? Describe sieve plates and explain their probable function. What is cuticle? Explain what is meant by meristematic tissue. What is an annual ring? What is the function of the medullary rays? Describe the cells of which these rays are composed. Are tracheal tubes found in gymnosperms? In angiosperms? Are tracheids found in angiosperms? In gymnosperms? Why is it advantageous to the plant to have larger tracheids and more or larger tracheal tubes in the spring wood than in the summer wood?

THE PLANT AS A WHOLE

BEFORE studying the structure of the principal plant organs, we shall consider their arrangement and their relation to each other in the plant body of a number of typical seed-bearing plants.

READING ASSIGNMENT:

Holman and Robbins, pp. 49–67.

MATERIAL FOR STUDY:

1. Whole plants of some herbaceous species such as flax (*Linum*).
2. Branches of cherry, prune, or plum (*Prunus*), or of willow (*Salix*), or other woody plant having alternate leaves and stipules.
3. Branches of maple (*Acer*), of olive (*Olea europea*) or other opposite-leaved woody plant.

DIRECTIONS FOR WORK:

1. Examine the plant furnished you and note:
   a. the division of the plant into a subterranean part, the root, and an aerial part, the shoot;
   b. whether there is a single main root (**primary** or **tap root**) with smaller **lateral roots** (**secondary, tertiary,** etc.) or, instead, a number of principal roots of about the same size with branches arising from them;
   c. whether the branch roots arise at regular intervals on the main root or are irregular in their origin;
   d. that the shoot consists of two sorts of structures, stems and leaves. If flowers or fruits are present, bear in mind, what will be more fully explained later, that the flowers and fruits are generally considered to be made up of modified leaves or parts of leaves.
2. If more than one stem arises from the upper end of the primary root or root system, choose what appears to be the principal stem and cut away the others, leaving only about an inch of each. Then note:

a. the division of the stem into **nodes** (regions from which leaves arise) and **internodes** (region devoid of leaves or of any evidence of leaf attachments);

b. with the aid of the dissecting microscope, the **leaf scars** on the lower part of the stem where leaves have fallen off;

c. lateral buds in the **axils** of leaves (the angles above the leaves formed by the leaf and stem). These buds are sometimes small and relatively inconspicuous. Look carefully for them);

d. where the branches arise relative to the leaves.

3. Can you come to any conclusion as to the relation between branches and axillary buds?
4. Make a somewhat diagrammatic **drawing** of the plant, showing:
   a. the whole root system;
   b. several nodes and internodes at the base of the shoot;
   c. several nodes and internodes about halfway up the shoot; and
   d. the upper 3 or 4 inches of the plant.
5. Make a detail **drawing** (at least twice natural size) of not less than two internodes and three nodes of an herbaceous plant with attached leaves. Another **drawing** on the same scale should show the origin of a branch and its relation to the leaf.
6. **Draw,** natural size or larger, a branch of *Prunus* or *Salix* bearing at least six leaves. Show lateral and terminal buds, stipules and stipule scars, and the four uppermost leaves. Draw only the bases of the petioles of the lower leaves.
7. Make similar **drawings** of a branch of *Acer* or *Olea.*
8. Make **diagrams** to show the leaf arrangement (phyllotaxy) in *Prunus* and in *Acer* or *Olea.* In these diagrams the successive nodes should be represented by concentric circles, the smallest representing the node nearest the tip. A cross line should be used to indicate the position of the leaf or leaves at each node.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Geotropism of Roots and Stems

Observe seedlings of corn or wheat which, after germination had just begun, were placed in a Petri dish, a little distance from its center, and held in place by means of a moist disk of stiff blotting paper, slightly larger than the dish and pressed firmly against the seeds. The dish should be placed on edge, and kept in the dark between class periods, the cover being held firmly in place by a rubber band. The seedlings should be so placed in the Petri dishes that they occupy various positions relative to the perpendicular. A piece of gummed paper pasted near the edge of the cover will serve to make certain that the same part of the Petri dish is kept upward. After the primary root and the shoot have grown to be a centimeter in length, sketches of several of the seedlings should be made. The direction of gravity should be indicated by an arrow. Note the different reaction of the root and stem to the stimulus of gravity. What are the terms used to describe these different reactions?

2. Phototropism of the Shoots of Grass Seedlings

Observe seedlings of oats or of millet, grown in small pots in the dark until 1 or 2 centimeters above the ground and then placed 1 or 2 meters from a window and so shaded that light reaches them only from the window. Note any curvature which takes place, and **draw** seedlings, showing several stages in the curvature. Indicate by arrows the direction from which the light comes.

Questions

Of what two principal parts does the plant body of a typical seed-bearing plant consist? Of what two kinds of organs is the aerial part made up? What name is given to the zones of the stem from which the leaves arise? To the leafless regions between these zones? What is a leaf bud? Distinguish two kinds of buds according to their location on the stem. Describe the two common types of root systems and give the names of two plants having each type of root system. What relation exists between

leaf arrangement and bud arrangement? What are leaf scars? Stipule scars? Bundle scars? Name three kinds of buds according to their contents. Give four functions which stipules may perform and name a plant illustrating each function.

THE STEM

The stem of typical flowering plants (Spermatophyta) supports the leaves, carries to them the water absorbed by the root, transports food to the other parts for use or for storage, stores food, and in many cases performs other functions. In the case of most trees and shrubs, there is an increase in the diameter of the stem from year to year, corresponding to the increase in the number of leaves, and to the resulting increase in the need for water and for mechanical support. As they increase in diameter, the main stem (trunk) and branches of trees, and the stems of shrubs, develop a large amount of tissue (mainly wood) for support and conduction. As one might expect from the variety of functions which it performs, the stem is a structure of considerable complexity.

Reading Assignments:

Holman and Robbins, pp. 68–128.
Stevens, Chapters II and III.

Material for Study:

1. Permanent stained preparations of longitudinal sections through the terminal bud of Dutchman's pipe (*Aristolochia*), honeysuckle (*Lonicera*), or other plant.
2. Stained longitudinal and cross sections of internodes of different ages from the stem of *Aristolochia*, *Platanus*, apple, or other woody dicotyledon.
3. Shoots of figwort (*Scrophularia*), of alfalfa (*Medicago sativa*) or other herbaceous plant.
4. Stained cross and longitudinal sections of the stem of Indian corn (*Zea mays*).

Directions for Work:

1. At the tip of every main or branch stem, as at the tip of every root, there is a group of cells which by their repeated divisions give rise to new cells and thus contribute to the growth

in length of the stem. These groups of dividing cells are spoken of as the **growing points.** We shall speak of the tissue of which they are made up as the **primordial meristem.** Since the cells of the growing points are thin-walled and delicate, and since the growing points are of .great importance to the plant, there is always provision for their protection from injury. The growing point of the root is protected by a root cap, a thimble-like mass of cells which is produced in front of the growing point. The growing points of stems are protected by the rudimentary leaves (**leaf primordia**) which have been formed at the growing point. These leaf primordia overlap and, together with the growing point and a number of nodes and short internodes, form the bud.

Draw in outline, on a large scale, a longitudinal section of the growing point of *Aristolochia.* Include the four youngest leaf primordia. Examine the sections from which this drawing was made and find a young axillary bud in the axil of one of the older leaves of the bud. **Draw** one of these, including the petiole of the subtending leaf. In these two drawings no cells need be shown.

2. Of the cross sections of *Aristolochia* or other dicotyledonous stem on the slide or slides furnished you, choose that one in which the vascular bundles are smallest. **Draw** a diagram of this section showing in correct proportions the tissues and regions listed below, as far as it is possible to identify them. The dissecting microscope may be used. Label each tissue and region.

Epidermis

Primary cortex
- Collenchyma
- Cortical parenchyma
- Endodermis (starch sheath), a single layer of cells

Pericycle
- Bast fibers
- Parenchyma

Vascular bundles
- Phloem
- Fascicular cambium
- Xylem

Medullary rays

Pith

In making this diagram no cells need be drawn except the large vessels in the xylem portion of the bundles, but the area occupied by each tissue should be accurately shown.

3. A similar **diagram** should then be made of a section in which the **interfascicular cambium** has just begun to make its appearance between the **vascular bundles.** This diagram should be on the same scale as the first. State briefly, below the diagram, what tissues have increased in extent relative to the other tissues.

4. With h. p., find a portion of the interfascicular cambium which shows clearly how this cambium is produced by tangential walls formed across the medullary ray cells. **Draw** on a large scale.

5. Make a **diagram,** on the same scale as the other two diagrams (2 and 3) of a section of a stem several years old. In addition to the tissues and regions seen in the youngest stem section and the interfascicular cambium, the following should be located and shown in the diagram:

Cork (outer bark).
Phellogen (cork cambium).
Annual rings in the xylem.
Layers of old phloem which have been crushed by the pressure resulting from the increase in diameter (secondary growth) of the stem.
Stone cells (sclerenchyma cells).

Below this diagram, list the changes which have taken place in the extent and character of the different tissues since the first appearance of the interfascicular cambium. (See 3 above.)

6. Make a number of cross sections from the tender upper portion of the stem of *Scrophularia* or *Medicago sativa.* Mount these in water and, finding the thinnest, identify as many as possible of the different tissues which you have previously encountered. **Draw** a large-scale diagram showing the tissues and regions present, and label it completely. Cells need not be shown except in the case of the larger vessels of the xylem.

7. **Draw** a diagram of a cross section of an internode of the stem of *Zea.* Use l. p. or dissecting microscope. Not all of the vascular bundles in the section need be shown, but in a segment of from $\frac{1}{8}$ to $\frac{1}{4}$ of the entire area, every bundle should be drawn. No cells need be shown in this diagram.

8. Make a **drawing** (h. p.) of one-half of one of the bundles as seen with h. p. Before starting to make this drawing, be sure that you have found a bundle which shows the details of structure

as well as any in the section. Then reproduce the form of the cells, their arrangement, and the thickness of their walls, as accurately as possible. The following parts and tissue elements should be shown:

Phloem { Sieve tubes / Companion cells

Xylem { Annular vessel / Spiral vessel—sometimes lacking / Pitted vessels

Bundle sheath

Intercellular passage

9. **Draw** also a few cells of the epidermis and of the tissues just below it as seen with h. p.

10. Examine with l. p. and h. p. the longitudinal sections of corn stem. Find the different tissue elements seen in the cross sections. Make **drawings** of a portion of one of each of the types of vessels found in the xylem.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. The Rise of the Transpiration Stream

a. Observe the leafy branches displayed in the laboratory. Some of these will be placed with their lower ends in water. Others will not be supplied with water. Note that some of those in water have been ringed, i.e., all the tissue outside the cambium has been removed from a portion of the stem above the water, the wound being covered with soft paraffin, wax or vaseline. Which branches show signs of wilting? What do you conclude as to the portion of the stem which is most important in water conduction?

b. Observe also the leafy and translucent stems of *Impatiens* or other plant with translucent stem (touch-me-not) the lower ends of which have been severed from the roots and immersed in a deeply colored solution of eosin or other dye. What do you conclude from an examination of the stems (held between the observer and the window) and of the leaves, as to the tissue which conducts water in these plants? Examine cross and longitudinal sections of the stems microscopically to see if you can find further evidence of the correctness of your conclusion.

c. Observe also the experiment in which a leafy shoot is tightly fitted into a water-filled tube, the lower end of which is immersed in a vessel of mercury. The water in the tube has been boiled. Why must boiled water be used? Make a drawing of the apparatus, state fully what takes place, and explain the result. Also compute the pull exerted upon the water in the tube. This can be done by measuring the height of the mercury column above the surface of the mercury outside the tube and computing the pressure in grams per square centimeter necessary to support such a column. Bear in mind that the normal atmospheric pressure of 1033.3 grams per square centimeter supports a mercury column (in a mercury barometer) of 760 millimeters.

d. A leafy branch (of a woody plant) from 40 centimeters to a meter in length, which has been placed with the cut end in water immediately after removal from the plant, has several centimeters of the lower end cut off under water. The stem is then placed in a strong eosin solution and left for fifteen minutes to half an hour (record the time) in a sunny place. The stem will then be split lengthwise and the distance to which the eosin has risen will be measured. Then the rate of movement may be computed. Observe what tissues of the stem conduct the solution. This may best be done by examining cross sections with the microscope. The average rate of two similar leafy stems should be compared with the average rate of two stems from which the leaves have been removed, but which are otherwise similar to the two leafy branches.

2. Tissue Tension

a. Observe and explain the difference in length of the tissues of the central and outer portions of a succulent stem or petiole when they are separated from one another. Suitable for this purpose are long straight pieces of rhubarb stalks (petioles of *Rheum*), or of the peduncles (flower stalks) of *Amaryllis* or *Richardia* (calla). The outer tissue should be removed in long strips, some of which should be intact and may be left attached for a short distance at one end of the stalk. If the stalk bends after the outer tissue has been removed from one side only, explain the cause of this bending.

b. Observe whether a ring of tissue separated from the cambium of a poplar (*Populus*) or willow (*Salix*) stem can be forced to span completely, as before, the woody cylinder from which it was removed. To remove the band of tissue, two cuts about 2 or 3 centimeters apart should be made with a sharp knife, clear around a branch from 3 to 6 centimeters in diameter or larger. These two cuts should be connected by a short longitudinal incision. Then, if all the cuts have extended clear to the wood, the tissues outside the wood may be removed as a continuous strip.

Questions

By what is the growing point of a stem protected? Describe the structure of a leaf bud. Is there any difference in structure between a terminal and a lateral bud? If so, explain the difference. Do all the buds of a tree grow and open every year? Describe the structure of the cells of the primordial meristem of a stem. Can you distinguish nodes and internodes within the bud? If so, how? Of what three regions is the vascular bundle of a dicotyledon or gymnosperm composed? Name all the regions where parenchyma is to be found in a cross section of a year-old *Aristolochia* stem. Why is interfascicular cambium needed even early in the development of the woody stem? How and from what tissue does it develop? How does the fascicular cambium originate? Explain the structure and function of collenchyma. Of bast fibers. Where is the endodermis? Of what tissue region does it form the inner boundary? What is the function of cork? What other tissue does it replace? To what substance in its cell walls does it largely owe its relative impermeability to water vapor and other gases? Are its cells mostly living or dead? How does it originate and increase in thickness? What are lenticels and what is their function? Where do we find annual rings? To what structural differences are they due? What is the function of stone cells? Where may they be found? How and from what kind of cells are they formed? What is heart wood? Sap wood? Which decays the more rapidly? Why? What part of the wood is principally responsible for conduction of sap? Contrast the structure of a typical herbaceous stem with that of a woody stem, such as that of *Aristolochia*, paying special attention to the relative extent of

each tissue. Contrast the distribution and structure of the vascular bundles in a typical dicotyledonous stem and a monocotyledonous stem like that of *Zea mays*. To what extent and how do typical monocotyledonous stems increase in diamater? In what way is it advantageous to the plant that the earliest differentiated vessels are usually annular or spiral? Name the principal functions of the stem. What structural differences would you expect to find between the stem of a creeping plant and that of an erect one? In what way can you demonstrate the fact that the upward flow of water is through the xylem? What would be the immediate effect, on the leaves, of the removal of all the tissues outside of the cambium from the stem of a growing plant?

THE ROOT

THE structure of young roots is simpler than that of young stems. It is also true that there is a greater uniformity in the structure of the roots of various plants than in the structure of their stems. In the case of plants which continue to grow for several years, the older portions of the root may develop cambiums, and as the result of secondary growth come to have much the same structure as old stems. In the roots of annual plants and in the younger portions of the roots of various plants which live more than one year, there is a much greater similarity in structure than in the stems of the same plants.

READING ASSIGNMENT:

Holman and Robbins, pp. 129–156.

MATERIAL FOR STUDY:

1. Young seedlings of radish (*Raphanus sativus*) and of wheat (*Triticum*).
2. Water-grown cuttings of wandering Jew (*Tradescantia*).
3. Stained cross sections of the root of flag (*Iris*).

DIRECTIONS FOR WORK:

1. Place a radish seedling on a slide in a drop of water. Handle the seedling only by the first leaves (**cotyledons**) and do not permit it to be exposed to the dry air of the laboratory for more than a few seconds after taking it from the container where it has grown. These two precautions are necessary to avoid injury to

the delicate **root hairs.** **Draw** the entire seedling on a large scale as seen with the dissecting microscope. Place the drawing on the sheet so that the root tip points downward and in making the drawing give particular attention to the length and distribution of the root hairs.

2. Make a similar **drawing** of a wheat seedling.

3. Remove, with the least possible injury to the root hairs, the tips of a number of *Tradescantia* roots. Mount these in water under a cover glass and study with l. p. and h. p. **Draw** the end of one of the roots showing the **root cap,** growing point, and other features which can be seen near the tip with l. p.

4. **Draw** a portion of the root showing part of the zone of root hairs as seen under l. p. Then **draw** several root hairs, together with the epidermal cells from which they arise, using h. p. Mount a small root in 20 per cent cane sugar solution and observe, under h. p., the progress of plasmolysis in the younger root hairs. **Draw** a plasmolyzed root hair.

5. Examine a stained cross section of *Iris* root under the dissecting microscope and with l. p. Find the following tissue groups and tissues and make a **diagram** on a large scale showing the location and extent of each:

a. The **epidermis,** a single layer of cells with the remnants of root hairs. When this part of the root was younger, these served for the absorption of water and nutrient salts from the soil;

b. the **cortex,** consisting of many layers of parenchyma, **the cortical parenchyma** (beginning just below the epidermis), and of a single ring of conspicuous cells (the **endodermis**) with the inner and adjacent walls very much thickened. Note that several layers of cortical cells just below the epidermis (the **hypodermis**) are of different character than the rest of the cortical parenchyma. They are often suberized in older parts of the root;

c. the **pericycle,** a single layer of rather large, thin-walled cells just below the endodermis; and

d. the **vascular cylinder** made up of **xylem** and **phloem.** The xylem occupies the center of the cylinder and radiating "arms" of the same tissue extend outward, almost or quite to the pericycle. The **phloem** is in small masses which lie between the radiating arms of the xylem. In this diagram no cells need be represented except the cells of the endodermis and the larger vessels of the xylem.

6. **Draw** in detail, as seen with h. p., a narrow strip of the root section extending from the epidermis to the pericycle, and enough of the vascular cylinder to include one group of phloem cells and two of the radiating strands of the xylem. This drawing should include one of the **transfusion cells** (thin-walled endodermis cells which lie opposite each xylem arm). They are believed to permit the entrance of water into the xylem more easily than would the thick-walled cells which make up most of the endodermis.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Root Pressure

Observe from time to time, during a period of a week or ten days, the basal portion of a stem (probably of *Fuchsia*) which has been " decapitated " just above the soil and whose superior portion has been replaced by a long glass tube of small bore attached to the butt of the stem by rubber tubing. Note the rise of water in the glass tube, and record in centimeters the maximum height attained. On the assumption that a water column one meter high indicates a pressure of 1000 grams per square centimeter, compute the intensity of the root pressure in this experiment in grams per square centimeter. Obtain the inside diameter of the tube from the instructor and compute the quantity of water given out as the result of root pressure. In this computation it will be necessary to take into account whether there was any water in the glass tube at the beginning of the experiment.

2. Adhesion of Root Hairs to Soil Particles

Observe young radish (*Raphanus*) plants which have been grown in loose sandy soil and then carefully removed from the soil. The particles adhering to the root hairs will be even more conspicuous if the seedlings are grown in moderately coarse emery powder. State two ways in which the adhesion of root hairs to soil particles are of importance to the plant.

Questions

Compare the internal structure of a young monocotyledonous root and a young dicotyledonous root. Contrast the structure of a ten-year-old dicotyledonous root with a monocotyledonous

root of the same age. Of what advantage to plants is the possession of root hairs? Do all seed-bearing plants have root hairs? If not, give an example of a seed-bearing plant having no root hairs. Is a root hair a complete cell? Does every epidermal cell in the root hair zone have a root hair growing from it? Describe in detail the structure of a root hair and the epidermal cell from which it is an outgrowth, commenting particularly on the nature of the wall, the amount and distribution of the cytoplasm and the cell sap. What type of root system is characteristic of most monocotyledons? What is the other principal type of root system? Is it universal among dicotyledons? Compare the amount of mechanical tissue in a young root and a young stem. Compare the need for mechanical tissue in the young root and young stem. How are transfusion cells situated relatively to the xylem arms? What advantage to the plant results from this relation? Contrast the relative position of xylem and phloem in the young root and in the young stem (particularly in the dicotyledons). Explain how water and dissolved salts pass from the soil to the conductive tissue of the root. Give a clear account of the secondary growth in thickness of dicotyledonous and gymnosperm roots. Name in order (beginning at the tip) the zones of which the younger part of the root is made up. In what way would it be disadvantageous to the plant if branch roots emerged and root hairs formed much nearer to the root tip than is the case? Explain how branch roots originate and how they reach the surface of the root. Of what advantage to the root is the possession of a root cap? What tissue of the root is constantly adding cells to the root cap? Why is this necessary? What function, other than absorption, do the branch roots and root hairs perform for the plant? Do the older portions of the root system carry on absorption of water from the soil? If not, why not? Common salt is often placed about the roots of plants in order to kill the plants. Explain what happens. Why are the roots of bog or marsh plants generally near the surface?

THE LEAF

It is in the leaf that the process most characteristic of typical plants takes place. This process is the manufacture of certain complex organic foods, most commonly grape sugar, or glucose, from the simple inorganic compounds, carbon dioxide and water, which are secured respectively from the atmosphere and from the soil. To a very large extent, the functions of the stem and root are merely auxiliary to this function of photosynthesis which is carried on by the leaf. The foliage leaves are especially adapted in structure to absorb carbon dioxide and sunlight, which latter furnishes the energy which is necessary in order to form the foods, and which remains stored in the molecules of these foods as chemical energy. The leaf is also the special organ for transpiration or loss of water by the plant.

Reading Assignment:

Material for Study:

1. Leaves illustrating various leaf forms, lobing, compounding, and venation.
2. Entire plants of oats (*Avena*) or other large grass.
3. Leaves of *Fuchsia* or other leaves from which the upper and lower epidermis can be easily stripped.
4. Leaves of *Iris*, *Amaryllis*, or *Lilium*.
5. Cross sections of living leaves of privet (*Ligustrum*), box (*Buxus*), or other small-leaved shrub.
6. Stained and permanently mounted cross sections of leaves of *Amaryllis*, or of other leaves with large stomata.

Directions for Work:

1. If weather permits, each student should collect, in the course of a field trip conducted by the instructor, leaves illustrating all of the following descriptive terms, which will be defined by the person in charge of the laboratory:

simple	pinnately lobed	peltate
compound	palmately lobed	perfoliate
pinnately compound	parallel-veined	linear
bipinnate	net-veined	entire
palmately compound	palmately veined	serrate
lobed	pinnately veined	dentate
	sessile	

2. Make an outline **drawing** of (*a*) a simple, (*b*) a lobed, and (*c*) a compound leaf. One of these leaves should have stipules. Only the principal veins need be shown.

3. Make a **drawing,** at least natural size, which will show the characteristic features of the grass leaf. It may be necessary to omit part of the leaf blade and the sheath, but the leaf apex, ligule, auricles (if present), and both ends of the sheath should be shown.

4. Strip pieces of the epidermis from the lower and upper surfaces of the leaf furnished. Mount these with outer surface up and examine with l. p. Note the form of the epidermal cells and observe the **stomata** with their **guard cells.** Are the stomata equally numerous on both leaf surfaces? **Draw** on a small scale, as seen with l. p., approximately equal areas of the epidermis from the two sides of the leaf. These drawings may be somewhat diagrammatic. From 25 to 40 ordinary epidermal cells and 6 to 8 stomata (if they are present) should be shown in each drawing.

Draw two stomata and 6 or 8 epidermal cells from the lower surface as seen with h. p. This drawing should be on a large scale and should show the cell contents. Before starting to make this drawing, be certain that the focus and the adjustment of the mirror and of the iris diaphragm are such as to give the maximum clarity of detail.

5. Make a similar study of the epidermis from the two surfaces of a leaf of *Iris, Lilium,* or *Amaryllis.* Compare the distribution of the stomata on the two surfaces with the distribution of the stomata in the leaf just examined. **Draw** several stomata and a few of the ordinary epidermal cells from one surface.

6. **Draw** a cross section of some small leaf as seen with l. p. This drawing should be diagrammatic but should include the entire cross section. No cells need be drawn, but the following tissues should be outlined: **epidermis** (lower and upper), **palisade parenchyma, spongy parenchyma, midrib, lateral veins,** and **epidermal hairs** if present. Show also the **cuticle.**

7. Using the thin freshly cut sections of the same leaf, which will be provided, make a **drawing** (h. p.) of a portion of the section, showing in detail all the tissues from the upper to the lower surface.

8. In the stained leaf sections, find stomata which have been cut at right angles to the leaf surface. **Draw** one of these which

shows clearly the structure of the stoma and guard cells. Use h. p. and do not fail to show the cavity in the spongy parenchyma just below the stoma.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Determination of the Relative Rate of Transpiration from the Two Surfaces of a Leaf

a. Observe leaves the two sides of which are being compared, with respect to transpiration, by the cobalt chloride paper method. This comparison is made as follows: Small disks of filter paper, not more than 5 or 6 millimeters in diameter, are dipped into a 5 per cent cobalt chloride solution, which gives them a pink color, and are then dried in an oven. When dried they are found to be blue in color and they retain that color as long as they are prevented from absorbing water or water vapor.

One of these freshly dried blue disks is placed on the upper surface of a leaf which remains attached to a living branch. The disk is then covered with a round cover glass on the under surface of which, very near the edge, stopcock grease or other thick grease has been placed. When this is pressed down on the leaf surface it forms an air-tight chamber surrounding the blue disk. Care should be used to prevent the disk from being smeared with grease. A blue disk and cover glass are similarly placed on the lower side of the same leaf. Both cover glasses should be inspected carefully after they are put in place to be sure that air can not enter the spaces beneath them.

A record should be made of the time at which the experiment begins and of the periods which elapse before each of the disks changes its color from blue to pink. The ratio between these two periods is the reciprocal of the ratio of the transpiration rates from the two sides of the leaf. If these periods are different, explain the reason for the difference.

b. Observe two similar leaves (of the India rubber plant (*Ficus elastica*) or other plant with relatively large, rather thick leaves) one of which has been smeared on the upper surface, and the other on the lower surface, with a thin coating of vaseline. These leaves should be pinned up on the wall of the laboratory. Note which is the first to show signs of wilting and explain the reason for the difference.

2. Determination of the Amount of Water Transpired from a Whole Plant by Measuring the Loss in Weight

A well-watered potted plant should be so sealed that no water can be lost from the soil or pot. This can be done by immersing the pot and the base of the stem in a vessel of liquid paraffin which is just warm enough to be a liquid, or by wrapping the pot in paraffin paper or sheet rubber, the edges of which are tied around the base of the stem.

The plant should be placed in the sunlight for ten or fifteen minutes, and then weighed. After a subsequent period of half an hour in the sunlight, it should be weighed again. Corresponding determinations should be made of the loss of water in the shade. The first weighing should be made after the plant has been in the shade fifteen minutes, the second after an additional half hour has elapsed. The loss in weight in twenty-four hours should also be determined. If time is available, the loss in weight per square centimeter of leaf surface should be computed according to directions given by the instructor. Most of the loss of weight is due to transpiration. What two other processes might affect the amount of loss?

3. Demonstration of Necessity of Light for Starch Manufacture

A potted plant (*Fuchsia* is good) should be kept in the dark for twelve to twenty-four hours. Then one or more of its leaves should be covered with tin foil except for an opening which will permit light to fall on the upper surface of the leaf. This opening should be in the form of some letter or geometric figure. At the same time that the tin foil is adjusted, a leaf should be removed from the plant and placed in the dark. After three or four hours in direct sunlight or five or six in diffuse sunlight, the masked leaves should be removed from the plant, freed from the foil, and, together with the leaf removed at the beginning of the experiment, boiled in water for several minutes. The leaves should then be placed in alcohol until completely freed of chlorophyll. They then should be immersed in a rather weak solution of iodine in $\frac{1}{2}$ per cent solution of potassium iodide.

Describe the experiment and the results, giving the reason for each step.

4. Liberation of Oxygen During Photosyntheses

Observe water weed (*Elodea*), water milfoil (*Myriophyllum*), hornwort (*Ceratophyllum*) or other submersed fresh-water plants in a large beaker or battery jar placed in direct sunlight. Note the bubbles which are given off, especially from cut or broken ends of the stems, and which rise to the surface.

It is possible to demonstrate that this gas is oxygen by (1) fitting a funnel, of smaller diameter than the beaker or battery jar, with a short piece of rubber tubing, a pinchcock and a short glass tube, (2) inverting it over a considerable number of shoots of the water plants in the jar, (3) opening the pinchcock to permit the funnel to fill with water and then closing it again. If the jar is put in a sunny place the gas given off by the plants will soon accumulate in the narrow end of the funnel, the stem of which should be supported by a clamp. After a considerable amount of gas has been collected, opening the pinchcock will permit the escape of a stream of gas, and if a glowing splinter is placed in this stream it will either glow more brightly or burst into flame. Does this show that the gas in the funnel is pure oxygen? Justify your answer. Give the equation for glucose manufacture by green leaves.

5. The Preparation of a Crude Chlorophyll Solution and Examination of Its Absorption Spectrum

It is possible to dissolve out the pigments of the chloroplasts with alcohol and various other solvents, but not with water. An alcoholic solution can be prepared as follows: A considerable quantity of grass or other green leaves is cut into fine shreds, placed in a bottle (or better in an Erlenmeyer flask) and just covered with alcohol. The container should be loosely corked and immersed (cautiously if a bottle is used) in water at boiling temperature, which should be replaced with more boiling water as it cools. The alcohol should not be brought near a flame.

When the alcohol has taken on a deep green color it should be filtered into a large test tube or flask.

Note the difference in color when the solution is examined by transmitted and by intense reflected light. If a spectroscope is available, examine light which has passed through the chloro-

phyll solution and light which has not. Record the regions of the spectrum in which the light is less intense after it has passed through the solution. It should be borne in mind that the green solution contains a mixture of four pigments, chlorophyll *a*, chlorophyll *b*, xanthophyll, and carotin.

Questions

What is a simple leaf? Give an example (scientific name). What is a compound leaf? Give the (scientific) name of two plants having compound leaves. Explain the difference between net venation and parallel venation. Of what great group of seed-bearing plants is each type of venation characteristic? Name a plant (scientific name) illustrating each type. What is the difference between palmate and pinnate venation? Give examples. Which of the latter types of venation is found in pinnately lobed leaves? In palmately lobed leaves? State how a pinnately compound leaf may have evolved from a pinnately lobed leaf. Distinguish between a dentate and a serrate leaf margin. Make two sketches showing the difference. Many horizontal leaves have stomata on the lower side only; of what advantage is this distribution of the stomata to such plants? On which surface of the leaf are the stomata of floating leaves? Explain why this distribution is advantageous to such plants. What was the form of the ordinary epidermal cells which you studied? Did they have chloroplasts? Explain the probable relation of the chloroplasts of the guard cells to the opening and closing of the stoma. Explain the advantage to the plant of having the palisade parenchyma cells closely packed and provided with so many chloroplasts. Of what value to the plant are the air spaces in the mesophyll? What is the advantage in having these air spaces larger and more abundant in the lower part of the leaf (spongy parenchyma)? What is the cuticle, and why is it important? State at least three functions served by the veins. What tissue elements are found in the smallest veinlets? Explain fully how a typical leaf is adapted for transpiration; for photosynthesis. Name the different factors that may influence the rate of transpiration. Is transpiration useful to the plant? If so, in what way or ways? In the process of photosynthesis, what is the source of the energy? What are

the raw materials? The end products? The by-products? List the conditions which commonly affect the rate of photosynthesis. Which of the two processes, respiration or photosynthesis, goes on at the more rapid rate in the green plant? What evidence can you give for your answer?

THE FLOWER

Thus far we have studied only the vegetative organs of the plant, that is, the organs which perform the functions essential to the survival, growth, and development of the individual plant. We shall now turn our attention to the structures which, in the Spermatophyta, are concerned with the production by the plant of new individuals like itself. These structures are the flower, the fruit, and the seed. It is generally believed by botanists that the parts which make up the flower are not organs entirely distinct from those which make up the other parts of the shoot, but that the flower parts are merely specialized leaves.

Before taking up in the laboratory the study of a number of types of flowers, it is necessary that we become acquainted with certain features of flower structure which are common to most flowers, and with the meaning of certain terms commonly used in discussing flower structure. The student should read over the following paragraphs carefully and should learn the meaning of the terms which are printed in bold face type.

When flowers are borne singly, the flower stem is called the **peduncle.** In case of flowers borne in a cluster, the short stems of the individual flowers are called **pedicels.** The enlarged end of the peduncle or pedicel, which remains after the removal of all the flower parts, is called the **receptacle.**

In most flowers, the flower parts are arranged in four circles or whorls. The outermost whorl is made up of **sepals.** The next is a whorl of **petals.** Next comes a whorl of **stamens,** and the innermost whorl is made up of **carpels.** Collectively, the sepals make up the **calyx,** the petals make up the **corolla,** the stamens the **androecium,** and the carpels the **gynoecium.** The petals and sepals are both included under the term **perianth.**

Generally the carpels are fused to form a compound **pistil.** The basal portion of the pistil (generally enlarged) is the **ovary.** Within the ovary are the **ovules.** If pollination takes place,

these generally develop into seeds. The portions of the inside of the ovary wall from which the ovules arise are called the **placentae.** Above the ovary is the (generally slender) **style,** and terminating this, the enlarged and sometimes lobed or divided **stigma.**

The union with each other of the members of a whorl of flower parts is called **coalescence.** Thus, the carpels in most flowers have coalesced to form a **compound pistil.** There may be coalescence in other whorls also. The petals are often partly or entirely coalescent, and in many cases there is coalescence between the sepals. Stamens are not infrequently coalescent at their bases, and in one important family the upper portions (**anthers**) of the stamens are coalescent, although their bases are free.

The members of one whorl may become fused in part with those of another whorl. This is called **adnation.** Thus the bases of the stamens are often **adnate** to the petals and appear to grow out of the petals instead of out of the receptacle. Sometimes there is coalescence of the sepals and adnation of the calyx, corolla and stamens, so that the stamens and petals seem to be borne on the rim of a tubular calyx. When the adnation between the ovary and the other parts of the flower is complete, the sepals, petals, and stamens (as well as the style) appear to arise from the top of the ovary and the ovary is said to be inferior.

READING ASSIGNMENT:

Holman and Robbins, pp. 210–243.

MATERIAL FOR STUDY:

1. Flowers with all or most of the parts both **free** and **distinct.** The following are a few of the many flowers which may be employed: *Sedum, Cotyledon, Linum* (flax), *Zygadenus, Ornithogalum* (star of Bethlehem), *Trillium,* and *Tulipa.*
2. Sympetalous flowers with superior ovaries, such as *Pentstemon* (beard tongue), *Mimulus* (monkey flower), *Primula* (primrose), *Nicotiana* (tobacco) or, *Datura* (jimson weed).
3. Flowers with inferior ovaries, such as *Oenothera* (evening primrose), *Epilobium* (fireweed and willow weed), *Campanula* (bell-flower), and *Amaryllis.*

4. Flowers of *Lathyrus* (sweet pea), *Phaseolus* or other bean, *Lupinus* (lupine), *Robinia* (locust), or other papilionaceous flower.
5. Inflorescences of *Avena* (oat), or of other grass with large spikelets.
6. Flowers of *Helianthus* (sunflower), *Aster*, *Erigeron*, *Wyethia*, or any other genus of the Compositae (Sunflower Family) having both ray-flowers and disk-flowers.

DIRECTIONS FOR WORK:

1. In the case of a flower of the first of the groups mentioned above, **draw**:

a. The entire flower on a large scale, showing and labeling all the parts which can be shown in one drawing.
b. A longitudinal section of the flower made without cutting the ovary or ovaries.
c. Much enlarged views of a single sepal, a single petal, one unopened stamen (in two views showing the anther and filament in each) and one pistil.
d. An ovary split lengthwise and in cross section, showing the placenta, or placentae, and the ovules.
e. An open anther, as seen with the dissecting microscope. The drawing should show the method of **dehiscence** of the pollen sacs, and the escaping pollen.
f. A portion of the stigma as seen in longitudinal section under h. p. This drawing should be on a large scale and should show particularly the structure of the surface of the stigma.
g. Two or three pollen grains.

2. In the case of a flower of the second group:

a. **Draw** the entire flower, natural size or larger.
b. Then, using the same flower or another of the same species, slit the corolla lengthwise along one side, spread it open so that the relation of the flower parts to one another may be seen, and **draw** what you see.

3. Make a longitudinal section of a flower with inferior ovary and draw it on a large scale, showing particularly the position of the ovary and its relation to other parts.

4. In the case of one of the flowers in group 4 (*papilionaceous* flowers):

a. Carefully remove the parts of the corolla. (These are the **banner,** two **wings,** and the **keel**: the banner is the large upper petal; the wings, two small lateral petals; and the keel, a structure consisting of two slightly coalescent petals which enclose the stamens and pistil.) Note that each of the five petals is distinct at its base and separately attached to the receptacle. **Draw** these parts on a large scale. They should be arranged on the drawing sheet with the bases of the petals converging and with the parts of the corolla having the same relation as in the flower.

b. Also **draw,** on a large scale, the flower with corolla removed, showing pedicel, receptacle, calyx, stamens, and pistil in position.

5. Make a floral diagram of each of the four flowers studied. Directions for making these diagrams will be given by the instructor. Each sepal should be represented by a very slender crescent drawn in outline, each petal by a segment of a circle drawn with a single heavy line, and each stamen by a representation in outline of an anther in cross section. For each carpel a small circle should be drawn. Coalescence and adnation should be shown by means of dotted lines connecting the parts which are partially or entirely fused.

Study of a Grass Flower

6. The account given above of the flower parts, their arrangement, and their relation to each other applies to the flowers of the great majority of species of the Angiospermæ. A number of families of the Angiospermæ, however, have flowers which are of a very different type. Among these families are the Gramineæ (including the grains and other grasses). Since this family includes many of the most important of economic plants, we shall devote some time to the study of a grass flower.

The following account of the grass inflorescence and flower should be carefully read before beginning the laboratory work:

The inflorescence in the grasses consists of a number of groups

of flowers, each group called a **spikelet.** The main axis of the inflorescence to which these spikelets are attached, either directly or by branches of the main axis, is called the **rachis.** When the rachis is not branched, the spikelets being attached directly to the rachis, the inflorescence is called a **spike.** When the rachis is branched and its main branches again branch, once or more, the inflorescence is called a **panicle.**

The spikelet has a shortened axis, the **rachilla.** This axis bears a number of chaffy, two-ranked, overlapping structures. The two lowermost of these are larger than the others and enclose the rest of the spikelet. They are called the **glumes.**

The flowers are without sepals or petals and consist generally of three stamens and of one pistil with two styles or at least with two stigmas. The stigmas are feathery. There may be three or more flowers in a spikelet. Often, all but one of these flowers are without pistil or have rudiments only of stamens and pistil. Each flower of a spikelet is enclosed between **bracts,** which are structures something like the glumes, but smaller. The lower of these bracts is called the **lemma**; the upper, with its back turned toward the rachilla, is the **palea.** At the base of the ovary on the opposite side from the palea, there are often two small scales (**lodicules**), which swell up and force the bracts apart so that the stamens and styles may push out.

a. Make a **drawing** of an inflorescence of the grass furnished. This should be drawn on as large a scale as the drawing sheet will permit.

b. Dissect a single spikelet under the dissecting microscope and locate all the structures mentioned in the description above. Determine whether any of the flowers lack either stamens or pistil. Make a **diagram** showing the arrangement of the glumes, flowers, bracts, and flower parts in a whole spikelet.

c. **Draw** a single flower on a very large scale. In order to get a clear view of the essential flower parts, it will be necessary to bend back the lemma and palea so that the parts within are brought into view. *Do not attempt to make this drawing until you have made a good preparation in which all the structures can be seen distinctly.*

d. Remove a single stamen, including the filament, from an unopened flower, and mount on a slide without water or cover glass. Examine with l. p. and make a **drawing** of the stamen. This drawing should be at least $1\frac{1}{2}$ inches long.

e. Make a **drawing,** on the same scale, of a pistil which has been removed from the flower.

f. Cut off the stigmas from a pistil and mount them in water under a cover glass. Examine with l. p. and h. p. and **draw** several of the branches of stigma as seen with the highest magnification.

g. **Draw** several grains of pollen secured from open anthers.

Study of a Composite Flower

7. Another type of flower (besides the grass flower) which is very unlike the typical flowers of the angiosperms is that of the Compositæ or Sunflower Family. In the plants of this family, what is ordinarily called a flower is actually a group of flowers or an inflorescence (**head**) in which the separate flowers (sometimes called **florets**) are borne tightly packed on the expanded end (receptacle) of a common peduncle. In many of the Compositæ the flowers in a head are of two kinds: **disk-flowers,** which have a tubular and five-toothed (or five-lobed) corolla and occupy the center of the head; and **ray-flowers,** in which the corolla is split on one side and extended into a strap-shaped structure (**ligulate corolla**), which is toothed at the apex. In such heads the **ray-flowers** occupy the margin of the head, and the radiating ligulate corollas suggest the petals of an ordinary flower. In some Compositæ ray-flowers are lacking, and in others all the flowers have ligulate corollas.

Each flower of a head consists generally of (1) a pistil made up of two carpels and having an inferior ovary and a straight style with a two-parted stigma, (2) five stamens with filaments free from each other, but with the anthers united into a tube which surrounds the style, (3) a corolla of five petals, and (4) a calyx which is reduced to a mere ring of tissue or to a cluster of scales or bristles, collectively called the **pappus.** Stamens, or both stamens and pistil, are absent in the ray-flowers of many species.

a. Cut a flower head lengthwise and make a **drawing** showing the peduncle, receptacle, involucral bracts around the base of the head, and the two kinds of flowers. Not all of the disk-flowers need be shown.

b. **Draw** a single ray-flower and one disk-flower, considerably enlarged.

c. Carefully cut away one side of the corolla of a disk-flower and make a large **drawing** with the use of the dissecting microscope. Show clearly the stamen tube and the style and stigma.

d. Dissect a ray-flower and determine whether stamens and pistil are present.

Questions

Name the essential flower parts. Of what parts is the perianth composed? Distinguish between an hypogynous and an epigynous flower. Name the whorls in a typical flower and state what function is served by each. What are carpels? Of how many carpels is a simple pistil composed? Name a flower having several simple pistils and one having a compound pistil. Name in order, from the base upward, the parts of a pistil. Of a stamen. What are the ovules? What is the part of the ovary to which the ovules are attached? What is the funiculus? What is coalescence? Adnation? What is meant by an inferior ovary? A superior ovary? Into what structure may the ovary develop? An ovule? To what vegetative organs do the flower parts correspond? Name three agencies which may bring about pollination. What agency is responsible for pollination in most grasses? In most other flowers? Explain the structure of a pollen grain. Describe the structure of a typical grass spikelet. Contrast the structure of some grass flower with that of a *typical* angiosperm flower. Explain why it is particularly advantageous that the stigma of grass flowers is large and much branched (plume-like). Of what advantage to the plant are the large and conspicuous petals of many flowers? Explain the difference between the vegetative and the reproductive activities of an organism. What is an inflorescence? What is a peduncle? A pedicel? Describe fully the structure of a disk-flower of a composite. Of a ray-flower.

THE FRUIT

PART of the pollen produced in the anthers of a flower normally reaches the stigma of some other flower of the same species. This is called pollination. On the stigma, the pollen develops a tubular outgrowth which grows down through the style into the ovary, where it enters one of the ovules. Two nuclei (the **male gametes**) are discharged into the ovule, and one of these fuses with the **egg cell,** or **female gamete,** and the other with another nucleus called the **endosperm nucleus.** The cell resulting from the fusion of a male nucleus with the egg cell is called the **zygote,** and it develops by cell divisions into the rudimentary plant, or **embryo,** found in every seed. The product of the other male gamete and the endosperm nucleus is a **fusion cell,** which divides and eventually gives rise to the **endosperm,** a mass of tissue which supplies food for the embryo's further development. In some seeds this endosperm makes up a considerable part of the mature seed. In other cases it is all used up by the developing embryo before the seed ripens.

The production of an embryo and of endosperm are not by any means the only results of fertilization. The tissues of the ovule are stimulated to renewed growth and form seed coats surrounding and protecting the embryo and endosperm when the latter is present.

The effects of fertilization extend even to the ovary, and in some cases to the receptacle, causing these to grow actively, and in many cases to undergo considerable change in form. The result is the production of a fruit. The fruit not only serves to protect the developing seeds, but often plays an important part in bringing about their dissemination.

We shall study a few of the principal types of fruits as illustrated by available material. The following is a brief classification of common fruit types:

I. In respect to texture or consistency, fruits may be divided into two groups, each including a number of types:

1. FLESHY FRUITS:

A. The **berry**—the ovary wall fleshy and enclosing one or more seeds, as in the grape or the tomato.

a. The **pepo,** a hard-rinded berry, such as the squash or cucumber.

b. The **hesperidium,** a berry with a leathery rind as the orange.

B. The **drupe** or stone fruit—the inner part of the ovary wall transformed into a stony tissue and surrounding the seed as in the peach.

C. The **pome**—largely made up of the fleshy receptacle, the ovary forming the core, as in the apple or the pear.

D. The **synconium**—consisting of a hollow receptacle, lined with numerous flowers, as in the fig.

2. DRY FRUITS:

A. **Dehiscent**—opening when ripe.

a. The **follicle**—simple fruit (one carpel) splitting along one side, as in the milkweed.

b. The **legume** (pod)—simple fruit splitting along two sides, as the pea.

c. The **silique**—consisting of two carpels which separate from a central partition, as the mustard or radish.

d. The **capsule**—formed from a compound ovary and having openings at or between the junctions of the carpels, as in the poppy, the morning glory, or *Iris.*

B. **Indehiscent**—not opening at maturity.

a. The **achene**—simple fruit with one seed free from the ovary wall, as in the buttercup.

b. The **caryopsis**—simple fruit with one seed grown fast to the ovary wall, as in the various kinds of grain.

c. The **nut**—ovary wall becoming a tough fruit wall, as in the acorn.

d. The **samara**—fruit with a wing-like outgrowth from the ovary wall, as in the seeds of the maple or the elm.

II. In respect to composition, fruits may be classified as:

SIMPLE, those which result from the ripening of a flower pistil, consisting of one enlarged ovary, with which some other flower parts may be incorporated,

AGGREGATE, those consisting of a cluster of enlarged carpels of the same flower crowded into a mass, as in the raspberry and blackberry,

MULTIPLE, those consisting of the enlarged ovaries of several flowers consolidated into one mass, as in the mulberry and pineapple.

READING ASSIGNMENT:

Holman and Robbins, pp. 244–261.

MATERIAL FOR STUDY:

Fruits of *Pisum sativum* (garden pea) or other unopened legume, *Prunus sp.* (peach or plum), *Malus sylvestris* (apple), or *Pyrus communis* (pear), and *Lycopersicum esculentum* (tomato).

DIRECTIONS FOR WORK:

1. Examine each of the fruits furnished you, and determine to which of the types, in each of the above classifications, each fruit belongs. Tabulate your conclusions in your laboratory notebook.

2. **Draw** a fruit of *Pisum* about $1\frac{1}{2}$ times natural size, and show the remnant of the style, the enlarged ovary, the calyx, and the withered stamens.

3. On the same scale as 2, **draw** a *Pisum* fruit split open and showing the inner side of both halves of the carpel with seeds, **funiculi,** and **placentæ.**

4. Make a drawing of a *Prunus* fruit cut lengthwise, showing the seed with its seed coat, the **endocarp** (**stone**), **mesocarp, exocarp,** the calyx, and the base of the style.

5. Make **drawings** of (*a*) an apple cut lengthwise through the center, and of (*b*) one cut crosswise. In the first drawing show clearly, and label, the stem, the flower parts at the opposite end from the stem, the vascular bundles of the receptacle, the "cells" (cavities) of the ovary, and the seeds. In the second drawing, show all the parts just mentioned except the stem (pedicel) and the flower parts.

6. Make a **drawing** showing a tomato in longitudinal section. This should show the cells of the fruit, the placentæ with attached seeds, the base of the style, the persistent calyx, and the stem (pedicel). **Draw** also a cross section of the tomato, showing the fruit (ovary) wall, the cells of the fruit, the placentæ, and the seeds.

7. Make **drawings** of the other fruits furnished you, showing the distinctive features of each.

Questions

Explain the changes in the pollen grain, and in the ovary of the flower and its contents, which normally follow pollination. Explain fully the structure of a mature embryo-sac. Distinguish between pollination and fertilization. Of what advantage to plants in nature is the development of the ovary wall into a fleshy layer? What are the two principal kinds of dry fruits? What is a seed? An embryo? How does the endosperm arise? Distinguish between a legume and a follicle. Between a berry and a drupe. Between simple, multiple, and aggregate fruits. What flower parts besides the ovary may take part in the formation of a fruit? What part of the apple flower becomes the fleshy part of the apple fruit? What do we call fruits of the apple type? Of what does the so-called "stone" of a peach or plum consist? From what part of the ovule are the seed coats derived? What is the difference between a nut and an achene? What name is given to the structures by which the seeds are attached to the placenta? Name and describe the three layers of which the ovary wall of the peach or plum consists.

Of what use to the plant is the food stored in fleshy fruits, such as the peach or the apple? Give examples of fruits that are especially adapted for dispersal by the wind. List all the plants that you know, the fruits of which are especially adapted for seed dispersal by the method of explosive discharge.

THE SEED

Reproduction in plants may be either vegetative or sexual. Vegetative reproduction is the production of a new individual by the separation of a part of the body of the plant and the growth of this separated part (whether it be bud, leaf, stem cutting, or

root cutting) into a plant like that from which it came. In sexual reproduction two sex cells, or gametes, of the same species unite to form a single cell called the zygote, which then develops by cell division into a new plant. In many cases a food-storing tissue (the endosperm) is formed and surrounds the rudimentary plant or **embryo** which develops from the zygote. In some seeds there is no endosperm at the time the seeds ripen, this tissue having been used up by the developing embryo.

READING ASSIGNMENT:

Holman and Robbins, pp. 261–289.

MATERIAL FOR STUDY:

Seeds, dry and soaked, of Lima bean (*Phaseolus lunatus*), Indian corn (*Zea mays*), wheat (*Triticum vulgare*), and castor oil plant (*Ricinus communis*).

DIRECTIONS FOR WORK:

1. Compare the soaked and dried seeds of each species as to texture of seed coats, color, size, and other characteristics. Then make two **drawings** of a soaked seed of each species. One drawing should show the broad side of the seed, and the other drawing the narrow side. The drawings should be from 2 to 3 times natural size, and the dissecting microscope should be used to examine the seeds before drawing. In the case of the wheat seed, both the groove side and the embryo side should be drawn, and the tuft of hairs (the **brush**) at the small end of the grain should not be overlooked. Of the two broad sides of the castor oil seed and the corn grain, the concave rather than the convex side should be shown in the drawings. Label all parts according to the instructions which will be given you.

2. Remove the seed coat from a soaked Lima bean, and note that there is no endosperm. Find the two **cotyledons**; the rudimentary shoot, or **plumule,** which lies between the **cotyledons**; the **radicle,** which develops into the primary root; and the **hypocotyl,** which is the portion between the radicle and the point of attachment of the cotyledons. In this seed it will be impossible for you to tell just where the radicle stops and where the hypocotyl begins. Carefully remove one of the cotyledons. Scrape off a little of the surface of the cotyledon, and mount in water to which a little iodine solution has been added. Examine

for starch under l. p. and h. p. There is also a large amount of protein in the bean cotyledons. **Draw,** at least twice natural size, the embryo with one cotyledon removed. Label all parts and do not fail to show the place where the one cotyledon was detached.

3. Carefully cut through the outer coat, or testa, of the castor oil seed in a line around the greatest circumference of the seed. Then, lifting off half of the testa, and noting the delicate inner seed coat (the **tegmen**), dissect away the endosperm, bit by bit, until the embryo is uncovered. This consists of a short radicle and hypocotyl at the **caruncle** end of the seed, and of two large, colorless, but leaflike cotyledons. One of the cotyledons should be removed, leaving the portions of the endosperm and embryo which remain in their normal position in half of the testa. Then make a **drawing** showing the embryo, endosperm, and seed coats, on a scale at least twice natural size. Crush a piece of the endosperm on a piece of white paper, and note the oily nature of the endosperm tissue and the translucent spot left on the paper. Oil is one of the principal forms of stored food in this seed.

4. Cut a soaked corn grain lengthwise and at right angles to the broad side of the seed. Examine the cut surface and find the embryo, which occupies the base and part of one side of the grain. Note the endosperm, of which the outer part (the **horny endosperm**), is darker in color than the inner white and powdery **starchy endosperm.** Note also the membranes surrounding the grain. The outer of these is the **pericarp** and is really a fruit coat rather than a seed coat. The corn "seed" and the so-called seeds of all the grains are really fruits consisting of a single seed to which the wall of the ovary, within which it was produced, has grown fast. Place some iodine solution on the cut surfaces, and note the change in the color of the starch of the endosperm. Make a **drawing** of the cut surface, showing all the parts. The drawing should be at least two inches in length. Label the **plumule** (stem end of the embryo) with its surrounding sheath, the **coleoptile,** the single cotyledon (called in the grains the **scutellum**), the embryo root called the **radicle,** and its enclosing sheath the **coleorhiza,** the endosperm, and the pericarp. Dissect out the entire embryo from a grain which has not been sectioned, and find all the parts seen in the section.

5. **Draw,** on as large a scale as the dimensions of the drawing

sheet will permit, three stages in the germination of the seeds of corn, castor oil plant, and Lima bean.

6. Crush in a little water, near one end of a slide, a small fragment of the endosperm from the vicinity of the scutellum of an old corn seedling, and cover with a cover glass. On the same slide, mount under another cover glass some of the endosperm from the same region of a freshly soaked ungerminated corn grain. Examine both mounts with h. p. and note what change in the starch grains has taken place during germination. To what is this change due? **Draw,** on a large scale, four or five starch grains from each mount. Place a small drop of iodine solution at the edge of each cover glass, and after a few minutes examine each mount and note the effect of the iodine on the starch.

EXERCISES ON THE PHYSIOLOGY OF PLANTS

1. Demonstration that Part of the Energy Produced by Respiration of Seeds is in the Form of Heat

Observe two Dewar flasks or thermos bottles in which are equal quantities of living and dead peas, and each of which is provided with a thermometer with bulb thrust down among the peas. In the preparation of this experiment, two lots of peas, weighing about 75 grams each, are placed in a 1 to 500 formalin solution for fifteen minutes. Both lots are then covered with boiled and cooled water in beakers or other containers in which the water was boiled. One lot is now brought to a boil and kept boiling for several minutes. After both lots have come to the same temperature, as shown by a thermometer which has been wiped several times with cotton dipped in alcohol, each lot is placed in one of the Dewar flasks or thermos bottles, which have been sterilized by being filled with strong (20 per cent) formalin solution and rinsed with sterile water. A sterile thermometer is then thrust down among the peas, and the neck of each container closed by placing cotton around the thermometer.

The thermometers should be observed daily for a week, and the temperature of the two lots of peas recorded. At the end of that time, the seeds should be poured out and examined for evidence of the presence of any bacteria or molds. Note whether either lot of seed feels warm to the hand.

Give an account of the experiment and explain the results.

The experiment sometimes works better if an open vial containing a piece of solid sodium or potassium hydroxide is lowered into each container before the thermometers are put in place. Why?

The student should refer to the exercise on page 9, showing that oxygen is essential for germination and growth, and to his notes on that experiment.

2. Loss of Material by Seedling, Due to Respiration

Two lots of 25 seeds each (Canada field peas, garden peas, or other seeds of good size and which germinate promptly) should be weighed to the second decimal point. The weights of the two lots of seeds should be nearly equal. One lot is then soaked and allowed to germinate between moist filter papers in a closed vessel. When the seedlings have developed radicles 1 or 2 centimeters long, they should be placed in a wide-mouthed bottle or jar which is closed by a cotton plug and contains bits of moist crumpled filter paper. After the seedlings have grown in the dark for a week, they should be removed and (together with the ungerminated lot) dried in an oven at 100° Centigrade for twenty-four hours, and weighed. The ungerminated lot should also be dried in the oven and weighed. From the weight secured and the original weight of the seeds, it will be possible to compute the per cent of water in the original air-dry seeds and the amount of material lost by respiration of the seedlings. Why were the seeds germinated in the dark instead of in the light?

Questions

What are gametes? What is the female gamete called in the flowering plants? The male gamete? Where is each found? What is a zygote? Where and how is it formed? Is a wheat grain a seed or a fruit? One can find on a corn grain the scar where the style broke off: Is that evidence that the corn grain is a seed or a fruit? Why do you so conclude? Is any endosperm produced in the development of the Lima bean? If so, why is there none in the mature seed? In our study of The Plant Body we learned that the plant is made up of three principal organs. To which of these do the cotyledons correspond? What would you expect to find in their axils? Can you actually find them? Into what part of the adult plant may the radicle develop?

Explain how you could tell, by sectioning the axis of the embryo, which part of it was plumule, which hypocotyl, and which radicle? Name all the functions which the cotyledons may perform. Which are performed by the cotyledons of the Lima bean? Of the scarlet runner bean? Of corn and wheat? What function is served by the plumule sheath in corn? Is the greater part of the root system of the corn plant developed from the radicle? If not, how does it arise? What functions are served by the cotyledons of the castor oil plant? Name two plants the cotyledon or cotyledons of whose seeds do not come above the ground during germination. What changes in the condition of the stored food in seeds is brought about by digestion during germination? Why are these changes necessary? To what class of substances do the substances which bring about digestion belong? Name four foods or classes of foods stored in seeds. Name the kind of enzyme concerned in the digestion of each. Give the characteristics of an enzyme. List the conditions necessary for germination, and show how modifying these conditions may affect the germination of seeds. What are the principal agencies for the distribution of seeds? How are seeds specially adapted for distribution by these agencies? Explain the effect on their germination, of scarifying, or breaking the seed coat, of certain seeds. Do all seeds retain their vitality for equally long periods of time? Can you name any of the factors that might affect the longevity of seeds?

Part II

CLASSIFICATION OF THE PLANT KINGDOM

In one of the most commonly used classifications of plants, the Plant Kingdom is divided into four principal groups (divisions), each of which consists of a number of classes. The lowest of these four divisions, commonly called the Thallophyta, includes a great variety of relatively simple plants, many of which are, in all probability, only very remotely related to each other. It seems very questionable whether all this motley assemblage of plants should be included within a single major division of the Plant Kingdom. In the case of the other three divisions (Bryophyta, Pteridophyta, and Spermatophyta), there is much less range of difference among the plants making up each division than in the Thallophyta. In many respects, the differences which exist among the plants included in the Thallophyta are as great as those existing among all the other plants in the Plant Kingdom.

A somewhat more modern classification divides the Plant Kingdom into two major divisions. Part of this newer classification, with the corresponding groups in the older classification, is given below. The genera listed in the center are illustrative of the different groups opposite which they stand.

OLD CLASSIFICATION	ILLUSTRATIVE GENERA	NEWER CLASSIFICATION
THE PLANT KINGDOM		**PHYTA**
THALLOPHYTA		**SPOROPHYTA**
ALGÆ		PHYCOPHYTA
Cyanophyceæ	*Glœocapsa, Oscillatoria, Nostoc, Rivularia, Cylindrospermum*	**Myxophyceæ**
Chlorophyceæ	*Protococcus, Scenedesmus, Volvox, Chlamydomonas, Ulothrix, Œdogonium, Closterium, Spirogyra, Vaucheria*	**Chlorophyceæ**
Phæophyceæ	*Ectocarpus, Nereocystis, Postelsia, Fucus, Sargassum*	**Melanophyceæ**
Rhodophyceæ	*Nemalion, Polysiphonia*	**Rhodophyceæ**
FUNGI		MYCOPHYTA
Myxomycetes	*Stemonitis, Leocarpus, Fuligo, Lycogola, Plasmodiophora*	**Myxomycetes**
Schizomycetes (Bacteria)	*Bacillus, Spirillum, Pseudomonas, Azotobacter, Bacterium*	**Schizomycetes**
		Eumycetes
Phycomycetes	*Saprolegnia, Rhizopus, Albugo, Phytophthora*	**Phycomycetes**
		Mycomycetes
Ascomycetes	*Peziza, Uncinula, Microsphæra, Sclerotinia, Saccharomyces*	**Ascomycetes**
Basidiomycetes	*Agaricus, Coprinus, Fomes, Polyporus, Lycoperdon, Ustilago, Puccinia*	**Basidiomycetes**
LICHENES	*Physica, Parmelia, Usnea, Cladonia, Ramalina*	LICHENES
BRYOPHYTA		**EMBRYOPHYTA**
		BRYOPHYTA
Hepaticæ	*Riccia, Marchantia, Fimbriaria, Porella, Anthoceros*	**Hepaticæ**
Musci	*Funaria, Sphagnum, Mnium, Atrichum, Polytrichum*	**Musci**
PTERIDOPHYTA		PTERIDOPHYTA
Filicinæ	*Pteris, Polypodium, Polystichum, Woodwardia, Adiantum*	**Filicinæ**
Equisetinæ	*Equisetum*	**Equisetinæ**
Lycopodinæ	*Lycopodium, Selaginella*	**Lycopodinæ**
SPERMATOPHYTA		SPERMATOPHYTA
Gymnospermæ	*Ginkgo, Cycas, Pinus, Abies, Sequoia*	**Gymnospermæ**
Angiospermæ	*Triticum, Lilium Nicotiana*	**Angiospermæ**

THALLOPHYTA

(Sporophyta)

ALGÆ

READING ASSIGNMENT: Holman and Robbins, pp. 327-377.

I. THE CYANOPHYCEÆ (Myxophyceæ or blue-green algæ)

PRINCIPAL CHARACTERISTICS:

1. There is no definite nucleus marked off from the rest of the protoplast by a nuclear membrane, as in most plants.
2. In addition to chlorophyll, there is generally an accessory pigment of a bluish color, called **phycocyanin.**
3. These pigments are not restricted to definite chloroplasts but are spread more or less diffusely through the whole protoplast or through the outer region of the protoplast.
4. There is no sexual reproduction. Multiplication is by cell division, followed by separation of the daughter cells in the case of the single-celled species. In the species where the cells are united in a colony, the larger colonies divide to form smaller colonies.
5. Many plants of this class produce a more or less thick gelatinous matrix around the cell or colony.

MATERIAL FOR STUDY:

1. Species of *Glœocapsa*, *Oscillatoria*, or *Nostoc*, and of *Anabœna*, *Cylindrospermum*, or *Rivularia*.

DIRECTIONS FOR WORK:

1. Mount a very little of the material of *Glœocapsa*. Examine with both l. p. and h. p. Then **draw,** as seen with l. p., a group of fifteen or twenty plants. Make several **drawings** on a large scale as seen with h. p. These drawings should include a solitary cell, a group of two cells, and one of four cells. Do not endeavor to show the cell contents in each cell, but represent it accurately in one or two of the cells. Show all the visible layers in the gelatinous matrix.

2. Mount a small quantity of *Oscillatoria* and **draw** a group of at least fifteen or twenty filaments as seen with l. p. Exam-

ine with h. p. and **draw** at least ten cells from the end of a filament. This drawing should be on a large scale. Do not attempt to draw the cell contents in the case of all the cells, but represent accurately the contents of three or four cells. Find several of the **hormogonia,** short segments into which the filaments break up and by means of which they multiply, and **draw** on a large scale. **Draw** also filaments in which these hormogonia are being formed by the death of a cell here and there. Examine material of a species of *Oscillatoria* which shows the movements executed by the filaments. Can the filaments move from place to place? Can they sway from side to side? Are they able to twist on their own axes? **Draw** diagrams illustrating all the different kinds of movements which you observe. In these, the original position of the filament can be shown in continuous lines, and the positions later assumed by dotted lines.

3. Examine under the microscope and make **drawings** of *Nostoc* and of *Rivularia, Anabœna,* or *Cylindrospermum.* In the case of each of these forms, make a low-power **drawing** of a group of at least ten filaments. **Draw** also a single filament on a large scale as seen with the h. p. In the event that the work on any of these forms has to be omitted, the student should acquaint himself with the principal characteristics of these forms and particularly with the structure and function of the **heterocysts** and **spores.**

II. THE CHLOROPHYCEAE (green algæ)

PRINCIPAL CHARACTERISTICS:

1. They possess definite nuclei.
2. They are clear green or yellow-green in color and do not have an accessory pigment masking the chlorophyll.
3. For the most part, the pigment in the cell is restricted to sharply defined regions of the protoplasm (the chloroplasts).
4. In relatively few of them is cell division (fission) the only method of reproduction. Many of them produce **zoospores** which are small protoplasts produced by the division of one of the ordinary protoplasts of the plant and able to swim by the lashing about in the water of

small threads of protoplasm called **cilia.** Still others have sexual reproduction by the fusion of sex cells (**gametes**) to form a **zygote** from which a new plant develops. When the sex cells are alike in structure and size, the plants are said to be **isogamous** and the fusion of the gametes is spoken of as **conjugation.** When the gametes are unlike they are called **sperm** and **egg.** Plants producing unlike gametes are said to be **heterogamous.** The fusion of egg and sperm is called **fertilization.**

5. For the most part the Chlorophyceæ do not secrete a gelatinous matrix as do most of the Cyanophyceæ.

MATERIAL FOR STUDY:

1. *Protococcus, Scenedesmus* or *Pediastrum.*
2. Vegetative and fruiting material of *Spirogyra, Œdogonium* and *Vaucheria.*

DIRECTIONS FOR WORK:

1. Examine a piece of wood or bark with *Protococcus* growing upon it. Remove some of the green growth by scraping lightly with scalpel which has been dipped in water. Mount in water under a cover glass. **Draw** several groups of the cells as seen with h. p. and on a large scale, showing clearly all the details of cell structure which you can make out. Make high-power **drawings** of colonies of *Scenedesmus* or *Pediastrum* if time and material are available.

2. Mount a small quantity of the *Spirogyra* furnished, taking care to injure the filaments as little as possible in transferring them to your slide. **Draw** a number of the filaments as seen with l. p. and on a relatively small scale. Then make two drawings of a single cell as seen with h. p. One of these should be a surface view and the other a median optical section. These drawings should be at least 3 inches long. **Draw,** still more enlarged, a short piece of one of the spiral chloroplasts, showing its structure in detail.

Make mounts of fresh or preserved material of conjugating *Spirogyra.* Find and **draw** on a large scale at least three stages in the process of conjugation, including one showing the mature zygospore. If material is available, examine and **draw** *Spirogyra* filaments showing lateral conjugation.

3. Mount and study fresh material of *Œdogonium*. **Draw** several filaments as seen with the l. p. Then **draw** in detail two or three cells on a large scale. The cells drawn should include one of those cells having at one end a number of ridges running around the outside of the cell wall. These so-called **ringed cells** are the only ones in the filament which divide. Watch for the escape of large, green, swimming bodies, the zoospores.

In fresh or preserved material of fruiting *Œdogonium*, find the swollen, more or less barrel-shaped cells within which the female gametes, or egg cells, develop. These structures are the **oogonia**, or female **gametangia**. When the oogonium is mature, there is a small opening or pore at one end through which the male gamete, or sperm, enters. Find two stages in the development of the oogonium. The later stage should show the pore clearly and the shrunken condition of the protoplast which is assumed when the egg cell is ready for fertilization. **Draw** the two stages on a large scale. Then find the **antheridia** or male gametangia, which are short cylindrical cells from $\frac{1}{4}$ to $\frac{1}{10}$ the length of a vegetative cell. **Draw** a group of the antheridia. The sperms are similar in form to the zoospores, but much smaller. They will not be so easy to find as the egg cells, but if any are seen they should be **drawn.** **Draw** also an oogonium with **oospore**—that is, with the thick-walled zygote which is produced when the egg cell is fertilized.

If fruiting material of an *Œdogonium* species having **dwarf males** is available, **draw** several of the dwarf males attached on or near the oogonia. **Draw** also several **androsporangia** within which the **androspores** (zoospores which give rise to dwarf males) are produced.

4. Mount and study fresh material of *Vaucheria*. **Draw** a few filaments (l. p.) to illustrate the method of branching and the general structure of the plant. Study (h. p.) a part near the tip of a growing filament, and make a **drawing** showing accurately the structure of a short portion. Study material showing the formation and germination of zoospores, and make **drawings** illustrating these processes. Examine material showing sexual reproduction. The gametangia are cells cut off from the main filament by cross walls. The gametangia may be sessile on the main filament or on short side branches, depending upon

the species studied. Note that the oogonia and antheridia are always close together. Make **drawings** to show how the gametangia are formed and also to show the structure of the oospore within the oogonium.

III. THE PHÆOPHYCEÆ (Melanophyceæ or brown algæ)

Principal Characteristics:

These are marine plants which grow, for the most part, on coasts where the water is relatively cool. The largest of the seaweeds are Phæophyceæ. The principal characteristics of the group are as follows:

1. They possess an accessory pigment of a brown color. This pigment is called **fucoxanthin.**
2. As in the Chlorophyceæ, there are definite nuclei and definite chloroplasts.
3. The Phæophyceæ generally grow attached to rocks, and many of them are found between high and low tide levels.
4. Although some are simple filamentous plants, many of the Phæophyceæ are much larger and more highly differentiated than any of the Chlorophyceæ, and certain of them suggest, in their complexity and large size, some of the flowering plants.
5. In some of the forms, zoospores are produced and sexual reproduction is isogamous. In other forms, such as the one we shall study in the laboratory, there are no asexual spores and sexual reproduction is brought about by the fusion of egg and sperm to form an oospore.

Material for Study:

Fresh or preserved fruiting material of *Fucus* sp., *Pelvetia*, or other related form.

Directions for Work:

The plant body of the Thallophyta is often spoken of as the **thallus,** and we shall use that term for the whole plant body of *Fucus*.

1. Examine an entire plant and note that the thallus consists of a disk-like **holdfast;** a forked (**dichotomously branched**) stalk, and a number of broad, flattened structures also dichotomously branched.

a. **Draw,** $1\frac{1}{2}$ times natural size, a holdfast and from **1 to** $1\frac{1}{2}$ inches of the stalk or stipe.

b. **Draw** a group of vegetative branches, including a portion of the stalk and showing the method of branching, the mid-rib, and the forking of the mid-rib at the tips of certain branches which have as yet not branched.

2. With the lens of the dissecting microscope, examine the very end of a vegetative branch and find one or two elongated depressions. **Draw,** 4 to 5 times natural size. At the bottom of each of these depressions there is a growing point.

3. Examine fruiting branches (these are swollen and covered with protuberances). **Draw** several of these, somewhat larger than natural size. The tips of the fruiting branches are called **receptacles.** The pores, which can be found near the center of each of the protuberances, lead into cavities in the thallus, called **conceptacles.**

4. Examine under the microscope thin sections across a vegetative branch, and note the complexity of the tissues as compared with any of the Thallophyta thus far studied. Make a **diagram** of the section, showing the **cortical layer,** and the central, less compact **medulla.**

5. Examine cross sections through a fruiting branch or, in case a dicœcious species is used, through both male and female branches. Make a **diagram** of one of the sections as seen under the dissecting microscope. This should show the form and distribution of the conceptacles. In these cross sections, study the conceptacles with h. p. and make **drawings** to show their appearance and the form and position of the oogonia, antheridia, and **sterile hairs** or **paraphyses.**

6. Make detail **drawings** of several antheridia, several paraphyses, and an oogonium. If eggs free from the oogonium are found, **draw** these also.

IV. THE RHODOPHYCEÆ (red algæ)

PRINCIPAL CHARACTERISTICS:

With the exception of a few forms which live in fresh water, these plants are marine, growing attached to rocks or other marine plants. They are common along the shore, but extend to greater depths than the brown algæ. The largest of the red algæ do not approach in size or complexity the largest of the brown algæ.

1. They are generally of a red or reddish color, due to the presence of an accessory pigment, **phycoerythrin,** which masks the chlorophyll.
2. The plants are always multicellular.
3. The cell walls are often much thickened and gelatinous.
4. No ciliated protoplasts occur; that is to say, zoospores are not produced and the male gametes are non-motile.

MATERIAL FOR STUDY:

Specimens of *Polysiphonia* mounted on cardboard or herbarium sheets.

Fresh or preserved material of **tetrasporic, antheridial,** and **carposporic** plants.

DIRECTIONS FOR WORK:

1. Examine a dry, mounted specimen of *Polysiphonia* and note that the plant is made up of delicate branching filaments. From the dried material or from a little fresh or preserved material in water, make a **drawing** showing the habit of the plant.

2. Mount a fragment of a tetrasporic plant in water on a slide. Examine with l. p. and h. p., and note the structure of the filaments and the method of branching. Each filament will be found to consist of a central row of cells surrounded by a single layer of cells. **Draw** a portion of filament showing the tip and the arrangement of the cells. Find and **draw** on a large scale (h. p.) several groups of **tetraspores** (asexual spores in groups of four) within the filaments.

3. Mount a little of a female (carposporic) plant. Find and **draw** one of the **cystocarps** (urn-shaped bodies) with contained **carpospores.**

The development of the cystocarp takes place as follows: The special reproductive branch, the procarp, consists of the carpogonium containing the egg, a slender trichogyne, the pericentral cell, and a group of auxiliary cells. After the fertilization of the egg and sperm, a number of cell fusions and nuclear divisions take place, resulting in the formation of a large multinucleate cell. From this arise the short branches, at the ends of which are formed the carpospores.

4. Mount a little of an antheridial plant and find the clusters of antheridia borne near the ends of some of the filaments. **Draw** one of these (h. p.).

Questions

What are the four major groups of the algæ? Give the main characteristics of each group. What is meant by an autophytic plant? Do all the algæ contain chlorophyll? What is an accessory pigment? Are accessory pigments found in all the algæ? How could you demonstrate that algæ carry on photosynthesis? What is the source of the carbon dioxide that is used in photosynthesis by submerged algæ? Which of the major groups of the algæ do you consider the most primitive? Why? What differences can you find between a cell of a blue-green alga and a typical cell of a flowering plant? In what way are blue-green algæ fitted to thrive in relatively drier places than are most of the other algæ?

Name two types of asexual and two types of sexual reproduction found in the green algæ. Why is the formation of zoospores an advantageous method of reproduction in the algæ? In what different ways may the cilia be distributed on the zoospores of algæ? Give examples. Which is the more specialized type of reproduction, isogamy or heterogamy? Give reasons for your answer. In what ways is the differentiation of gametes an advantage to the plant? What is a gametangium? Describe the gametangia of *Spirogyra*, *Œdogonium*, and *Vaucheria*. Which of these do you consider the more primitive? Are special food-storage organs found in the algæ?

In what sort of habitats are the representatives of the brown algæ found? In what way is the sexual reproduction of *Fucus* different from that of the forms which we studied in the green algæ? Is the large number of sperm cells in *Fucus* an advantage to the plant? Why?

How do the red algæ, on the average, compare in size with the brown algæ? Are the red algæ mostly marine or fresh-water plants? Are zoospores formed in the asexual reproduction in the red algæ? How do the sperm cells of *Polysiphonia* differ from those of *Fucus*? Is isogamy found in the red algæ? What is meant by the alternation of generations in *Polysiphonia*? How can you explain the difference in chromosome number in the cells of the tetrasporic plants and the sexual plants? Can you find any evidences of evolutionary development in the algæ?

Do you think the algæ form one unified, related group of plants, or a number of less closely related groups? Give reasons for your answer.

FUNGI

These are the heterophytic Thallophyta, that is, the Thallophyta that are without chlorophyll and are therefore unable to manufacture their own food. They may be either **saprophytes** (securing their food from the dead bodies of plants or animals or from the dead products of plants and animals) or **parasites** (securing their food from the living bodies of plants or animals).

READING ASSIGNMENT:

Holman and Robbins, pp. 378–444.

I. THE SCHIZOMYCETES (Bacteria)

PRINCIPAL CHARACTERISTICS:

This class of plants includes the simplest known organisms. They are probably only remotely related to the other three classes of the Fungi. The bacteria are unicellular organisms without definite nuclei. They multiply by fission. Some of them produce asexual spores, called **endospores,** which are formed singly within the ordinary cells. A considerable number of the bacteria are motile. With very few exceptions, the bacteria are heterophytic. Although the parasitic bacteria which cause disease have been particularly studied on account of their importance to man, by far the greater number of bacteria are not parasitic, but saprophytic. Some of these are of considerable importance because of the part they play in agriculture, in various industries, and in the decay of organic matter.

DIRECTIONS FOR WORK:

1. Mount a small amount of the white material from the teeth on a clean slide with a very small amount of water and cover with a cover glass. Examine with h. p. Adjust the diaphragm below the stage and the mirror until the bacteria making up the white deposit can be seen with the maximum clearness. Find as many different forms of bacteria as you can. These should include spherical forms (*Cocci*—singular *Coccus*), rods (*bacilli*—singular *bacillus*), and long thread-like forms.

2. Mount a small amount of the scum from the surface of an old algal culture in which decay has begun. Do not use an excess of the material but just enough to form a thin layer between the slide and the cover glass. Examine for various motile and non-motile bacteria. In such material actively moving spiral forms (*spirilla*—singular *spirillum*) can generally be found. Active bacilli are also frequently present.

3. Examine the roots of the legume (member of the pea family) plants furnished you and note the nodules of varying sizes. Draw a number of these nodules as they are arranged on the roots. Remove one of the nodules, crush under the cover glass and note under h. p. the material that oozes out. Are bacteria visible? If so, of what form are they?

4. Examine the stained bacteria mounted under the h. p. microscope set up by the instructor for demonstration. **Draw** a few of each of the forms mounted on these microscopes and label with the name of the organism in each case.

Demonstration on Bacterial Growth on Artificial Media

5. Much of our knowledge of the bacteria could never have been gained but for certain methods which have been developed for (*a*) the **isolation** of one of these minute plants from others, (*b*) the **culture** of these isolated individuals so that they may multiply, and (*c*) the **prevention of contamination** of these **pure cultures** by other kinds of bacteria. The instructor will demonstrate these methods in the laboratory and the student should write a full report of the demonstration in the laboratory notebook.

II. THE PHYCOMYCETES (algal fungi)

Principal Characteristics:

As the name suggests, these plants show striking resemblances to certain algæ, and it is probable that they are more closely related to certain algæ than to any of the fungi which we shall study later. In this group, the plant body is cœnocytic. Sexual reproduction is isogamous in some forms, in others heterogamous. There are some plants in the group which produce zoospores. As in the groups of fungi to be studied later, the plant is made up of branched filaments (**hyphæ,** singular, **hypha**), the vegetative hyphæ being spoken of collectively as the **mycelium.**

MATERIAL FOR STUDY:

1. *Saprolegnia*, growing on dead flies in water.
2. *Rhizopus nigricans*, plus and minus strains growing on moist bread.
3. *Albugo candida*, fresh or preserved material on *Capsella* or some other cruciferous host.

DIRECTIONS FOR WORK:

Saprolegnia

1. Make a habit **drawing** to show the appearance of the growth of *Saprolegnia* on the body of a fly. Mount a portion of the radiating hyphal growth, and study the hyphæ and the sporangia. Make a **drawing** to show the form of the sporangia. Can you distinguish the spores in the sporangia? **Draw** three or four zoospores. If oogonia are present, **draw** one showing the oospores.

Rhizopus nigricans

2. Make a habit **drawing** showing a piece of bread partly or entirely covered with the mycelium of *Rhizopus nigricans* (black bread mold).

3. Remove a very little of the surface of the bread at a place where the growth of the mold is still white. Mount in a drop of water on a slide and, with the needles, gently tease the mass apart. Place a cover glass over the preparation. Note the hyphæ, the cytoplasm, the vacuoles, and the absence of any cross walls. There are numerous nuclei in the cytoplasm, but they can not be distinguished without special staining. Make a **drawing** on a rather large scale and show all that you can see.

4. The sporangia within which the asexual spores are produced are, when mature, black spherical bodies borne on the upper ends of stalks called **sporangiophores.** These sporangiophores arise in groups from a common base which is attached to the substratum by means of a group of freely branching hyphæ. From the base of each group of sporangiophores an aerial hypha, or **stolon** generally extends. This stolon, when it comes in contact with the substratum, gives rise to another group of sporangiophores. The production of stolons suggests, though only superficially, the production of runners by certain of the higher plants, such as the strawberry. Remove with care a single group of the sporangiophores and mount carefully in water, to avoid, if possible, the rupture of the

sporangia and the breaking or tangling of the structures attached. Placing several small pieces of cover glass or of paper under the cover glass will prevent the material being crushed. **Draw** as seen under l. p. and show all the structures mentioned in the first part of this paragraph.

5. **Draw,** on a larger scale, a single sporangium with a portion of the sporangiophore. Within the sporangium is a wall (**columella**) which is curved and projects like a dome into the space inside the sporangium wall. Find a sporangium from which the sporangium wall has dissolved away, leaving the dome-shaped columella. Adhering to the columella there will probably be found a few of the spores which are formed by fragmentation of the protoplasm between the sporangium wall and the columella. Note whether any of the sporangium wall remains attached to the columella. **Draw** the columella with a portion of the sporangiophore.

6. Find and **draw** several stages in the development of the sporangium. Material for this should be taken from a portion of the mycelium that is still white.

7. Examine the spores with h. p. and note the markings on the spore wall (in order to see these it will be necessary to secure the most favorable illumination by adjustment of the mirror and diaphragm, and to focus carefully), and observe whether there is any difference in the size and form of the spores. **Draw** several spores, showing the points just referred to and also showing the cell contents.

8. Mount material of germinating spores which will be furnished by the instructor. This material is secured by sowing, a few hours before the laboratory period, a quantity of the spores in a decoction of bread in water. **Draw** germinating spores, showing the break in the wall where the germination tube emerges, and showing also several tubes of different lengths. In one case show in your drawing the appearance of the contents of the tube (protoplasm and vacuoles).

9. *Rhizopus* also reproduces sexually by conjugation, but only when the mycelia of two different strains grow together. The two strains are called by Blakeslee, to whom we owe our knowledge of the conditions for sexual reproduction in the plant, the **plus strain** and the **minus strain.** The instructor will furnish cultures which were inoculated with spores of each strain. From one of these

cultures take a small quantity of the mold and, teasing it apart in a drop of water on a slide, search for various stages in the process of sexual reproduction. The instructor will show by blackboard sketches how these stages may be recognized. **Draw** at least three stages, and label the **suspensors** (hyphal branches) at the ends of which the gametangia are produced; the gametangia; and the large, black, rough-walled zygospore which is produced by the fusion of the contents of the gametangia.

Albugo candida

10. **Draw** a portion of the host plant, *Capsella*, showing the blister-like infected areas. Cut a thin cross section of a leaf through one of these blisters, and make a **drawing** to show the chains of conidiospores which are formed underneath the epidermis of the host plant. Prepare cross sections of host material which shows the oogonia and oospores developed within the tissues of the stem. Make **drawings** to show the structure of the oogonium and several stages in the development of the oospore.

III. THE ASCOMYCETES (ascus fungi)

PRINCIPAL CHARCTERISTICS:

This group includes the largest number of species of any of the major groups of the Fungi. Many of the species are parasitic on seed-bearing plants. The most striking characteristic of the whole group is the production, somewhere in the life history, of special hyphæ or **asci** (sacs) within each of which are produced spores (**ascospores**), generally eight in number. The asci are in most cases produced within a fruiting body, which is called an **ascocarp.** Conidiospores are also produced in many forms. These are spores cut off in succession from the ends of special hyphæ.

MATERIAL FOR STUDY:

1. Growing cultures of *Saccharomyces cerevisiæ* (a yeast).
2. Apothecia of *Peziza* or similar cup fungus.
3. Fresh shoots of some flowering plant bearing mycelium and conidiospores of a powdery mildew.
4. Fresh or dried material of leaves bearing the perithecia of *Uncinula salicis* (willow mildew), *Microsphæra alni* (lilac mildew), or some other powdery mildew.

DIRECTIONS FOR WORK:

Saccharomyces

1. Mount a small fragment of a yeast cake and examine with h. p. Can you distinguish the yeast cells from the other constituents? Draw a drop of iodine solution under the cover glass and explain the difference in the staining reaction of the different structures found in the mount.

2. Mount a drop of a sugar or fruit juice solution, to which yeast has been added, and study the growing yeast cells found there. Make **drawings** to show at least three stages in the multiplication of the yeast plants by budding.

Cup fungi

3. Make a habit **sketch,** on a scale three or four times natural size, of the ascocarp (**apothecium**) of *Peziza* sp. or other cup fungus. Show the form of this fruiting body and the place on the under side where it was attached to the mycelium. In this saprophytic form the mycelium grows in soil or other substratum rich in organic matter.

4. Mount in water rather thin sections through the wall of the apothecium and examine with l. p. Note that a portion of the section is made up of elongated structures, all parallel to each other and at right angles to the surface, and that the remainder of the section is made up of closely interwoven hyphæ. Make a **diagram** of a portion of the section showing these two layers. The layer made up of elongated parallel structures is the **hymenium** which lines the inside of the apothecium. It consists of asci and sterile hairs or **paraphyses.**

5. Tear the section into small pieces by means of needles, and crush slightly by gentle pressure on the cover glass. Then find and **draw** a group of three or four asci and a number of the paraphyses. **Draw,** on a larger scale a single paraphysis and an ascus, showing the eight spores.

Powdery mildews

6. Examine the surface of a mildewed leaf under l. p. and note the superficial growth of the mycelium and the conidiophores.

7. Make a cross section of a mildewed stem or leaf, and mount in water. Some care will be necessary to prevent air bubbles

from being retained by the mycelium of the mildew. **Draw** a portion of the section to show the mycelium and the conidiophores as seen with l. p.

8. **Draw** a leaf bearing perithecia of some mildew. Examine an area of the leaf bearing many perithecia (dark brown, spherical structures within which the asci of the mildew are produced) under l. p. The leaf should be strongly illuminated from above. Make a **drawing** showing the perithecia in position.

9. With a scalpel which has been dipped in water, scrape off a number of the perithecia and examine with l. p. and h. p. Choose one of the perithecia which shows well the characteristic elongated appendages. Examine it with illumination from the mirror and also with illumination coming only from above. Make a large **drawing** of the structure.

10. Break open some of the perithecia. This should be done by gentle pressure exerted upon the cover glass by means of the point of the scalpel or forceps; the perithecia should meanwhile be observed with l. p. After the wall of the perithecium is broken, the asci will protrude through the break. Make a **drawing** of the ruptured perithecium showing the asci.

11. Find in the preparation detached asci in which the ascospores may be seen. **Draw** several of these on a large scale. Find also ascospores which have been freed from the asci and **draw** a number of these.

IV. THE BASIDIOMYCETES (fungi whose spores are borne on basidia)

PRINCIPAL CHARACTERISTICS:

This group contains many species, including numerous large and conspicuous forms. The Basidiomycetes may be roughly divided into three groups, viz., the **smuts,** the **rusts,** and the **fleshy fungi.** The smuts and the rusts are all parasitic on the higher plants and include the most destructive of the fungous parasites of economic plants. The fleshy fungi include the mushrooms and the bracket fungi. With few exceptions they are saprophytes. Some of them are of very great economic importance in that they cause decay in forest and fruit trees and in lumber.

MATERIAL FOR STUDY:

1. Oat stalks infected with *Ustilago avenae* (the loose smut of oats). Stalks of wheat infected with *Tilletia foetens* (the closed smut or bunt of wheat). Stalks of barley infected with *Ustilago hordei* (the loose smut of barley).
2. Leaves and stalks of oats (*Avena*) or other cereal plants showing the winter spores (**teleutospores**) and summer spores (**uredospores**) of *Puccinia graminis* or other species of *Puccinia*, a basidiomycete causing the serious disease called "rust." Stained and mounted sections of cereal leaves showing groups of teleutospores and uredospores on the surface of the host.
3. Leaves of barberry (*Berberis vulgaris*), a plant in whose tissues the parasite, *Puccinia graminis*, grows during a part of its life history. These leaves show on the lower and upper surfaces the characteristic structures (**æcidia** or "**cluster cups,**" and **spermogonia**) which the parasite produces on this host. Stained cross sections of infected barberry leaves.
4. *Puccinia malvacearum* on leaves of *Althea rosea* (hollyhock) or other member of the Malvaceae.
5. **Sporophores** of *Agaricus* sp., or other gill fungus.

DIRECTIONS FOR WORK:

Smuts

1. Examine the oat stalks furnished you and note that the floral parts of each spikelet have been almost entirely destroyed by the parasite. Note that within the glumes or the glume remnants there is found, instead of a seed, a mass of brownish-black dust. This dusty mass is made up of the spores of the fungus. **Draw** two or three of the spikelets, showing glume remnants and the dark spore mass. Mount some of the spores and study with h. p. **Draw** a few of the spores as seen under h. p., taking care to show as much as you can see of the spore wall.

2. Observe some of the smutted heads of barley furnished you and **draw** a head to show the effect of the disease. Examine the spores of the fungus with the microscope and note any differences between these spores and those of the oat smut. Illustrate any differences by **drawings.**

3. Examine heads of wheat that have been parasitized by

Tilletia fœtens and contrast them with smutted heads of the oats and the barley. This fungus infects only the ovary of the wheat plant and does not destroy the seed coat. It simply consumes the interior portion of the grain, including the embryo and the endosperm. The spores of the fungus form a dusty brown mass within the seed coat, and are set free when the seed coat is broken. Make a **drawing** of one of the infected heads of wheat, and then examine one of the grains, which are dark brown in color and distorted. Crush the grain and note the odor of the spores. Study the spores with the microscope (h. p.) and make **drawings** of several.

Rusts

4. Examine the wheat or oat stalks furnished by the instructor and find the black groups (**sori**) of teleutospores. **Draw** a portion of the stalk 2 or 3 times natural size and show several of the sori. The mycelium (vegetative hyphæ) of this fungus is within the tissue of the stem or leaf sheath. The teleutospores are produced on the ends of hyphæ just beneath the epidermis of the host. Their pressure raises the epidermis, and forms a blister. Finally the epidermis is broken through. Examine the teleutospore sori with the dissecting microscope or with the l. p. of the compound microscope and then **draw** one or two sori on a large scale, as seen when magnified. With a scalpel wet with water, remove some of the teleutospores and **draw** three or four on a large scale.

5. Examine material showing the sori of summer spores (uredospores). Make a **drawing** showing, as seen without the use of the microscope, an area of the host upon which are a number of these sori. **Draw** one of the uredospore sori as seen with l. p. Remove some of the uredospores with a wet scalpel and **draw** as seen under h. p. The uredospores are very easily broken off from their stalks, but it should be possible to make out the place of attachment of the spore to the stalk.

6. Examine the stained cross sections of rusted cereal leaves showing sori of uredospores and **draw,** on a large scale, a single sorus and the neighboring tissue of the host. Do the same with the sections through teleutospore sori.

7. Examine infected leaves of barberry and note the somewhat swollen yellow or orange areas on the under surface of the leaf,

and the corresponding areas on the upper side which are often somewhat darker in color. **Draw** the lower side of an infected leaf. This drawing should be at least twice natural size. Examine the affected area on the lower surface as seen with l. p. and note the small cups (æcidia) filled with orange spores and with edges projecting above the leaf surface. **Draw** a small portion of the leaf surface with several of the æcidia as seen under the microscope. On the opposite surface find with l. p. the openings of the **spermogonia.** Using stained cross sections of infected barberry leaves, make a diagrammatic drawing (cells need not be drawn) to show the comparative size and the form and position of the æcidia and the spermogonia, as well as the effect of the parasite on the thickness of the leaf.

8. Study leaves of hollyhock, or other member of the Malvaceæ, that are infected with *Puccinia malvacearum.* Make a drawing to show the teleutspore sori on a portion of the leaf. Remove part of one of these sori, mount, and draw several of the teleutospores on a large scale.

Gill fungi

9. Make habit **drawings,** natural size or slightly enlarged, of a young sporophore (**button**) and a mature sporophore of *Agaricus* sp. In the older sporophore show the **stipe** (which, before the mushrooms were collected, was attached at its lower end to the mycelium which grows in soil or other substratum rich in organic matter), the expanded, umbrella-like portion (the **pileus**); and the **gills,** which are borne on the under side of the pileus. Note whether there is a ring (**annulus**) on the stipe a little below the pileus.

10. Split a button and a mature sporophore lengthwise and **draw** one of the halves of each with the cut surface uppermost. Can you determine what changes are involved in the development of the button into a mature sporophore?

11. Remove the stipe from a mature sporophore and make a **drawing** of the lower surface of the pileus to show the arrangement of the gills.

12. Mount a cross section of a gill and examine with l. p. and h. p. Make a **diagram** to show the central layer, consisting of a loose felt of interwoven hyphæ, and the layer forming the surface of the gill. This surface layer is the hymenium and is made up

of **basidia** with which sterile filaments are sometimes mingled. The structures making up the hymenium are parallel to each other and at right angles to the surface of the gill.

13. With h. p., search along the edges of the sections of the gills for basidia showing **sterigmata** and for spores still attached to sterigmata. Make **drawings** on a large scale to show these features.

14. Make **drawings** showing in detail several of the spores that have been shed.

15. Each student should observe the demonstration, in the laboratory, of other forms of fleshy fungi. Note the different devices by which a great hymenial surface is secured in the different types of sporophores. Whereas in the gill fungi the hymenium is spread over the surface of the gills, in the tooth fungi, an extensive surface is secured by the formation of long tooth-like outgrowths, and in the pore fungi the same result is attained by means of tubular pits or pores in the lower surface of the sporophore. In the puff balls the hymenium lines the surfaces of the many small chambers within the sporophore. Explain how each of these different types is adapted for the dissemination of the spores. It has been computed that one sporophore of a common mushroom may bear as many as 5 billion spores.

LICHENES

Principal Characteristics:

Each of the members of this group consists really of two plants growing together in intimate association and forming an "organism" of characteristic form, quite unlike that of either of the two component plants growing alone. The two component plants are an alga and a fungus. The algal component multiplies vegetatively within the fungus mass. The fungus component reproduces generally by means of ascospores borne in apothecia, since it is generally an ascomycete. A few tropical lichens have a basidiomycete, instead of an ascomycete, as a fungus component. In addition to the reproduction of the fungus by spores, **soredia** are formed by some lichens. These soredia are tiny, dust-like pieces of the lichen, each containing a few algal cells and a few fungus hyphæ. Under favorable conditions these will develop into new lichens.

MATERIALS FOR STUDY:

Specimens of *Physcia, Parmelia, Usnea, Cladonia,* or other lichens, showing apothecia and soredia if possible.

DIRECTIONS FOR WORK:

1. Study a fresh specimen of one of these lichens, or one that has been dried and then moistened before use. Make a habit **drawing,** showing the thallus and the reproductive organs of the fungus and the portions which give rise to soredia if soredia are present.

2. With a sharp razor or razor blade, cut sections through the thallus and make **drawings** to show the position and relationship of the algal cells and the fungus filaments. Also make vertical sections through an apothecium and examine these sections microscopically, noting that they are made up of asci and paraphyses. **Draw** two or three of the asci and several paraphyses.

3. If soredia are found, mount some of these in water, examine with the microscope, and make a **drawing** showing the structure of one.

QUESTIONS

What are some of the characters that are common to both the blue-green algæ and the bacteria? How are spores formed in bacteria? What are some of the beneficial activities of bacteria? What is meant by a parasitic organism? A saprophytic one? What are some of the harmful activities of bacteria other than the causing of diseases in man and other animals? Why are the nodule-forming bacteria on the roots of legumes said to be beneficial organisms? Why is the growth of putrefactive bacteria usually accompanied by unpleasant odors? What is a cœnocyte? In what ways are the Phycomycetes especially like certain members of the green algæ? Define the following terms: mycelium, host, substratum, hypha, sporangiophore, columella, cœnogamete. What is the food of the *Rhizopus,* which you have seen grown in the laboratory? Can the mycelium take in solid particles of food? Is the starch of the bread absorbed directly as food? If not, how? What group of the green algæ have the same type of sexual reproduction as is found in *Rhizopus?*

Are zoospores or non-motile spores the more common method of asexual reproduction in the fungi? Can you

suggest a reason? What is an ascus? An apothecium? A perithecium? Explain why the powdery mildews are said to be obligate parasites. Are yeasts usually parasitic or saprophytic? Is alcoholic fermentation carried on in the presence of an abundant supply of oxygen? Explain. How does budding, as seen in the yeasts, differ from fission? Which form of reproduction, sexual or asexual, would most effectively serve as a method of multiplication of a powdery mildew during the growing season?

What are the three main groups of the Basidiomycetes? Name three smuts that cause important plant diseases. Name all the different spore forms in the life history of *Puccinia graminis*? What is meant by heterœcious? In what group of the fungi is heterœcism commonly found? How may this be of importance in the control of the disease caused by the fungus? Are mushrooms commonly parasitic or saprophytic? Where are bracket fungi commonly found growing? Describe the following structures: stipe, annulus, sterigma, and basidium, as seen in a common mushroom. What is meant by symbiosis? Why is a lichen said to be an example of symbiosis? To what order of the Chlorophyceæ does the alga of the lichen which you have studied belong? To what class of the fungi does its fungus belong?

BRYOPHYTA

The fungi include, with a few exceptions, all the heterophytic plants. With the exception of the Myxomycetes, they have in all probability been developed from the algæ. The principal characteristics which distinguish the various fungi from the algæ seem to have arisen as adaptations to the parasitic or saprophytic mode of securing food, or to their habit of growth in other media than water. The fungi do not seem to have taken any part in the evolution of the higher plants from the algae.

The Bryopyhta probably include the nearest relatives among autophytic plants, of the autophytic Thallophyta, or algæ. It is not unlikely that plants resembling in a general way some of the living members of the Bryophyta bridged the gap, in the evolution of the higher plants, between the algæ and the Pteridophyta.

The characteristics of the Brypohyta which stand in most striking contrast to those of the algæ are:

1. the presence in the life history of two distinct and clearly defined phases: the **gametophyte generation** having "x" chromosomes in its nuclei and giving rise to male and female gametes, and the **sporophyte generation,** developing from the zygote and having "2x" chromosomes in its nuclei;
2. the production of antheridia in which the numerous sperms are surrounded by a wall made up of many cells instead of being surrounded, as in the algæ, simply by the cell wall of the single cell which produces the sperms.
3. the production of a special, more or less flask-shaped, multicellular structure called the archegonium, within which the egg is produced and retained until fertilization. This is in sharp contrast with the oogonium of the higher algæ which is not multicellular but in which the egg or eggs are merely surrounded by the cell wall of a single cell.

READING ASSIGNMENT:

Holman and Robbins, pp. 445–475.

MATERIAL FOR STUDY:

1. Gametophyte plants of *Marchantia,* bearing **gemmæ cups.** Young male and female gametophytes of the same plant. Older female plants bearing sporophytes.
2. Sterile and sexual plants of *Porella.* Older female gametophytes bearing sporophytes.
3. Leafy plants of *Funaria hygrometrica, Atrichum, Mnium,* or some other moss. Older plants bearing sporophytes.

Marchantia

DIRECTIONS FOR WORK:

1. Carefully remove from the soil a mature plant of *Marchantia* bearing the asexual reproductive bodies, or gemmæ cups. **Draw** both dorsal and ventral views. In the first, show the method of branching, the mid-rib, and the position of the gemmæ cups. In the ventral view, show the rhizoids and scales.

2. Examine the upper surface of the thallus with a dissecting lens and note its divisions into rhombic patches. In the center of each is a pore which allows the exchange of gases. **Draw** a few of these areas showing the pore.

3. With a wet scalpel, remove a few of the gemmæ from one of the cups. Examine under l. p. and h. p. **Draw** three or four of these (l. p.).

4. The antheridia and archegonia are borne on special branches of the male and female gametophytes. These branches are upright structures bearing disk-shaped receptacles at their summit. The antheridial receptacle has a lobed margin and the antheridia are imbedded in the tissue of its upper surface. The archegonial receptacle consists of eight or ten finger-like rays. The archegonia may be found hanging neck downward in the notches between the rays. **Draw** a young male and a young female plant showing the male and female branches.

5. From freshly cut or permanently mounted sections made through the antheridial branch, **draw** an antheridium (h. p.) showing the stalk, the wall, and the spermatogenous tissue of the antheridium.

6. From freshly cut or permanently mounted sections made through the archegonial branch, make a **drawing** of the archegonium, showing the venter, the neck, and, if possible, also the egg cell and ventral canal cell.

7. **Draw** a female plant showing a fully matured female branch.

8. From a section through the female branch, **draw** a mature sporophyte plant showing foot, stalk (**seta**), and **capsule**.

9. Dissect out the contents of a mature capsule and **draw** (h. p.) a few spores and elaters.

Porella

10. Examine a sterile plant of *Porella*. Note the two types of leaves. **Draw,** twice natural size, a plant showing its general habit. **Draw,** at least 4 times natural size, a leaf of each of the two types.

11. Examine a male plant of *Porella*. The male plant may be recognized by the antheridial branches, which are pale yellowish-green branches with small closely imbricated leaves. **Draw** an antheridial branch and show its relation to the rest of the plant. Carefully dissect out in water the antheridia from one of these branches. The antheridia will be recognized as globular bodies with comparatively long stalks. **Draw** an antheridium, showing the structure of the wall, the sperm-forming tissue and the stalk (h. p.).

12. The female plants are somewhat harder to recognize. Archegonia are formed at the tip of young branches and in order to obtain them, the branches must be carefully dissected. The archegonia are flask-shaped bodies composed of a neck and venter in which the egg may be found. **Draw** an archegonium to show these structures (h. p.)

13. **Draw** a female plant with the sporophyte attached. Find a ripe capsule which shows the method of dehiscence. **Draw.**

14. Remove some of the contents of a mature capsule. **Draw** a few spores and elaters as seen under h. p.

Moss

15. Carefully remove a *young* moss plant from the soil by means of forceps, place in water on a slide, and clean away as much as possible of the attached soil. Then cover with a cover glass and **draw** the whole plant, showing the stem, leaves, and rhizoids as seen under the dissecting microscope or with l. p. of the compound microscope. **Draw** in detail and on a large scale a portion of several rhizoids. Search for pieces of **protonema** (alga-like, branched green filaments which are produced by the germinating spores and which in turn give rise to the leafy plants). **Draw** some of the protonema, showing at least four or five cells with their contents as seen under h. p.

16. **Draw** a mature male shoot of *Funaria* or other moss, 4 to 5 times natural size and showing the characteristic arrangement of the leaves at the tip.

17. Make an outline **drawing** on a large scale of a moss leaf. **Draw** also several of the cells of the leaf as seen with h. p.

18. With the needles, dissect out the antheridia and paraphyses from the tip of a male branch and **draw** several of each of these structures (under h. p.). If active sperms are discharged from any of the antheridia, make a **drawing** showing how they escape. Study the structure and movements of the sperm.

19. Dissect out the archegonia from the tip of a female plant. Examine these and find the stalk, venter and neck of an archegonium. By proper illumination and careful focusing, the cavity within the venter and the egg cell may be made out. Just above the egg cell in unopened archegonia the ventral canal cell (a sister cell of the egg) can often be clearly seen; and within the neck a row of cells called the neck canal cells.

Endeavor to find archegonia that are opened at the end. In such archegonia the neck canal cells and the ventral canal cell have been expelled and the passage from the open end of the archegonium to the egg is free. Make **drawings** to show the structure of the archegonium.

20. **Draw** a female gametophyte shoot of *Funaria* or other moss (on a large scale) with the sporophyte plant attached. The sporophyte plant consists of the foot (a structure which grows into the tissue of the apex of the female gametophyte, attaches the sporophyte to the gametophyte, and absorbs water and some food for the use of the sporophyte), the seta or stalk, and the capsule. The capsule bears at its tip the **calyptra.** The calyptra is nothing more than the archegonium, from the fertilized egg cell of which the sporophyte developed. The archegonium at first enlarges with the growth of the contained embryo sporophyte, but is finally broken away and carried up on the capsule when the seta undergoes rapid elongation. In your drawing label all the parts mentioned.

21. Make a detail **drawing** on a large scale of the capsule and of the calyptra after its removal. Carefully remove the cover or lid of the capsule. This lid is called the **operculum.** Make a **drawing** of it on a large scale.

22. Remove the operculum and then cut off the end of the capsule and mount the end under a cover glass. Examine and **draw** some of the **peristome teeth** which surround the mouth of the capsule.

23. Tease apart with the needles, in water, a dry mature capsule of *Funaria* or other moss, remove the larger fragments, cover with a cover glass, and study the spores with h. p. **Draw** several of these on a large scale. These spores have " x " chromosomes in their nuclei and belong, therefore, to the gametophyte generation.

Questions

What are the two main divisions of the Bryophyta? In what ways are *Riccia* and *Marchantia* like the Thallophyta? In what ways does *Porella* show an evolutionary advance over *Riccia*? Why are the names gametophyte and sporophyte applied to the contrasting generations in the Byrophyta? Which is the haploid generation? Which the diploid? Which is the

independent generation in *Riccia* and *Marchantia*? What is the difference between an antheridium as seen in the Thallophyta, and those of the Bryophyta? What is the difference between an oogonium and an archegonium? Do any of the Bryophyta form motile spores? Why are the liverworts always found in relatively moist places? How does the sporophyte of *Anthoceros* exhibit an evolutionary advance over that of the other liverworts? What is the name of the structure that is formed when the spore of the moss germinates? What differences in structure can you find between the rhizoid of a moss and the rootlet of a seed plant? What similarity in function can you find between the two? Why do moss plants never grow to more than a few inches in height? Is the sporophyte generation of a moss entirely dependent on the gametophyte generation? Is the calyptra composed of gametophyte or sporophyte tissue? What regulates the movements of the peristome teeth?

PTERIDOPHYTA

The sporophyte in the Bryophyta never becomes entirely independent of the gametophyte, but always remains attached to it and secures its water and at least part of its food from it. As we pass from the more primitive to the higher forms, there is, however, (1) increase in the complexity of the sporophyte, (2) a reduction in the amount of spore-producing tissue as compared with sterile tissue in the sporophyte, and (3) a tendency for the sporophyte to become more nearly independent of the gametophyte (in the mosses the sporophyte is green and is able to absorb carbon dioxide and manufacture part of its own food).

In the Pteridophyta the sporophyte plant develops a root by which it establishes its own direct connection with the soil, and thus eventually becomes an independent plant, although for a time it remains connected with the gametophyte by a foot through which it absorbs food and water. The sporophyte plant in the Pteridophyta becomes much larger and more complex than the gametophyte and is much longer lived.

Reading Assignment:

Holman and Robbins, pp. 476–508.

MATERIAL FOR STUDY:

1. Portions of the mature sporophyte of *Polypodium* sp. showing rhizome, roots and leaves (**fronds** or **sporophylls**) bearing groups (sori) of sporangia on the under surface.
2. Fronds of *Polystichum, Woodwardia* or other fern, bearing sori with covering membranes (**indusia**).
3. **Prothallia** (gametophytes) of some fern.
4. Sterile shoots of *Equisetum* (common horsetail) attached to the rhizomes.
5. Fertile shoots bearing strobili.
6. Sporophyte plants of one or more species of *Selaginella* with strobili (cones) made up of **microsporophylls** and **megasporophylls.**

DIRECTIONS FOR WORK:

Fern

1. **Draw** the portion of a mature *Polypodium* sporophyte furnished you. The drawing should be on as large a scale as the dimensions of the drawing sheet will permit. Label all parts. In this drawing the under side of one sporophyll should be shown.

2. **Draw** a single **pinna** (leaflet) of a sporophyll of *Polypodium* showing the venation and the sori. This drawing should be on a scale about twice natural size.

3. **Draw** a pinna of *Polystichum* or *Woodwardia* with mature sporangia, on the same scale as " 2."

4. **Draw,** much enlarged, a single sorus of *Polystichum* or *Woodwardia* with mature sporangia, on the same scale as " 2."

4. **Draw,** much enlarged, a single sorus of *Polystichum* or *Woodwardia* and some of the surrounding area of the leaf as seen under the dissecting microscope or l. p. of the compound microscope. This should show the mature sporangia and the indusium on a larger scale than " 3."

5. From very young, as well as from mature sori, remove, with the needles or the point of the scalpel, sporangia in various stages of development. **Draw** at least three stages, including a mature sporangium.

6. **Draw,** as seen under h. p., several ripe spores.

7. **Draw** several stages in the development of young prothallia, as shown by plants which have been grown from spores

sown on the surface of water or a mineral nutrient solution. These sporeling plants will be furnished by the instructor.

8. Carefully free a prothallium from soil particles and mount it, with rhizoids up, under a cover glass. **Draw** on a scale such that the longest diameter is at least 2 inches. This drawing should show the form of the prothallium (gametophyte plant), the form and arrangement of the cells over a small area, the structure of the rhizoids, and the location of the antheridia and archegonia. If the prothallium bears only antheridia or only archegonia, find one bearing the gametangia absent from the first, and **draw.**

9. Secure from the instructor a gametophyte to which a sporophyte is attached. Make a **drawing** showing the relation of the two plants and showing the following organs of the young sporophyte: the root, one or more leaves, and the short stem which will develop into the rhizome.

Equisetum

10. Make a large-scale **drawing** of a sterile shoot of *Equisetum* with its attached rhizome.

11. Make, on the same scale as in " 10," a **drawing** of a strobilus from a fertile shoot and enough of the shoot to show the scale-like leaves at the nodes and the arrangement of sporophylls on the strobilus.

12. Remove one of the peltate sporophylls and mount under the dissecting microscope. **Draw** as seen from the side, showing the stalk and the sac-like sporangia.

13. Mount spores dry, and study under l. p. Breathe gently on the slide and watch the movements of the elaters. **Draw** spores to show the elaters, both when closely wound about the spore and when unwound.

Selaginella

A number of the fern allies, belonging also to the Pteridophyta, produce two kinds of spores, **microspores** and **megaspores.** Since this production of two kinds of spores (**heterospory**) is characteristic of all the Spermatophyta, its occurrence in the Pteridophyta is important from the standpoint of the evolution of the seed-bearing plants. On that account we shall study a heterosporous pteridophyte, *Selaginella,* in the laboratory.

14. Make a habit **drawing** of a branch of Selaginella, showing: the method of branching, the special root-bearing outgrowths (**rhizophores**) of the stem, the form and arrangement of the leaves, and the strobili (cone-like groups of microsporophylls and megasporophylls).

15. **Draw** a short length of stem, about 4 times natural size and including six or eight leaves.

16. **Draw** a single strobilus on the same scale.

17. Carefully remove the sporophylls from a strobilus until both a microsporophyll (with round or oval sporangium) and a megasporophyll (with four-lobed sporangium) are found. **Draw** each kind of sporophyll on a large scale and show the sporangium in each case.

18. By slight pressure, crush the sporangia sufficiently to free the spores. **Draw** several microspores and one megaspore on the same scale. **Draw** also one or two microspores on a much larger scale.

Practice in the Determination of Some of the Commoner Genera of Ferns

Using the key given below (which has been adapted from Maxon and other sources), determine the genus of each of the ferns furnished you. The instructor will give directions as to the use of the key.

Sori dorsal, not marginal, separate on veins.
- Indusium lacking or abortive and obscure.
  - Sterile fronds simply pinnatifid.
    - Fertile fronds similar to the sterile, leaf-like. → *Polypodium* (Polypody)
    - Fertile fronds much contracted, segments pod-like. → *Onoclea* (Sensitive Fern)
  - Sterile fronds 2–4 pinnate or pinnatifid.
    - Fertile fronds similar to the sterile, leaf-like. → *Phegopteris* (Beech Fern)
- Indusium present.
  - Sori round or oval.
    - Indusium orbicular, centrally peltate. → *Polystichum* (Christmas Fern)
    - Indusium roundish, reniform, attached at the sinus. → *Aspidium* (*Dryopteris*) (Shield Fern)
    - Indusium inferior, cup or involucre-like, and cleft into narrow segments. → *Woodsia*

Sori oblong, or linear to lunate.

Sori large, tumid, in a row parallel to the mid-rib. — *Woodwardia* (Chain Fern)

Sori small, separate, parallel to the oblique lateral veins, straight or horseshoe-shaped, fronds 1–3 pinnate. — *Asplenium* (Spleenwort)

Sori marginal, or submarginal (at or near the apex of the veins) in a few cases sporangia completely covering the veins.

Sporangia following the veins throughout. — *Gymnogramma* (Gold Fern)

Sporangia at or near the apex of the veins.

Sori distinct, under a more or less modified reflexed lobe of the frond. — *Adiantum* (Maiden Hair)

Sori soon confluent into a more or less continuous marginal band.

Plants large and coarse. — Pteris (Bracken)

Plants mainly small.

Segments of sterile fronds pubescent. Vein ends of fertile fronds distinctly thickened. — *Cheilanthes* (Lace Fern)

Segments of sterile fronds glabrous. Vein ends or fertile fronds scarcely or at all enlarged. — Pellea (Cliff Brake)

Questions

What are the three classes in the Pteridophyta? In what way do the pteridophytes show an advance over the bryophytes? Which is the more conspicuous generation in the ferns? What is the fern gametophyte called? Why is it necessary for this gametophyte to grow close to a moist surface? Where are the gametangia borne on the fern gametophyte? What are the four primary organs of the fern embryo? Which of these develops into a permanent structure? What is the rhizome of the fern? Where is it usually found? What are the leaves of ferns commonly called? What is the name given to a cluster of sporangia on a fern leaf? What is an indusium? Name two genera of ferns that have indusia, and two that have not. Are the spores of *Polypodium* all alike? What term is applied to those pteridophytes in which all the spores are alike? Name an example of the pteridophytes in which the spores are not all alike. Why is *Equisetum* called scouring rush? Where are the sporophylls borne? How many sporangia on each sporophyll? Are the spores all alike? Describe the gametophyte. How might the elaters aid in spore dispersal?

In what way does *Selaginella* show an evolutionary advance over the true ferns? Which contains the greater number of spores,

the microsporangium or the megasporangium? What is the cluster of sporophylls of *Selaginella* called? Is the gametophyte generation independent at any time in its development? Which is the larger, the male or the female gametophyte? What structure is found in the embryo of *Selaginella* that is not found in the embryo of the ferns? Is this evidence of an evolutionary advance? Give reasons for your answer.

SPERMATOPHYTA

In the seed-bearing plants the sporophyte has become much more complex and highly differentiated than in the Pteridophyta. The gametophyte, on the other hand, has been reduced even further than in the heterosporous Pteridophyta. The reduction of the gametophyte is greater in the angiosperms than in the gymnosperms. In both these classes, however (Gymnospermæ and Angiospermæ) the female gametophyte (**embryo sac**) develops within the megasporangium (**nucellus** of the **ovule**). The embryo sporophyte arising from a fertilized egg cell of the female gametophyte also develops within the megasporangium (ovule). This embryo, with a nutritive tissue (the **endosperm**), which surrounds it, and the seed coats (developed from the nucellus wall and the **integuments**) constitute the seed.

Reading Assignment:

Holman and Robbins, pp. 509–549.

Material for Study:

1. Tips of *Pinus* branches, bearing young megasporangiate strobili (**carpellate** cones).
2. Tips of *Pinus* branches bearing young microsporangiate strobili (**staminate** cones).
3. Mature megasporangiate cones of *Pinus*.
4. Pine seeds with wings attached.
5. Flowers of *Lilium* or other genus of the Liliaceæ.
6. Stained, mounted sections of ovules of some angiosperm, showing the four megaspores.
7. Stained, mounted sections of the ovary of *Lilium*, showing several stages in the development of the female gametophyte (embryo sac).

8. Stained, mounted cross sections of anthers of *Lilium*, showing the microsporangia before and after dehiscence.

DIRECTIONS FOR WORK:

Gymnosperms

1. **Draw,** about natural size, the tip of a pine branch with young megasporangiate strobili attached.

2. Make a **drawing,** on the same scale, of the tip of a pine branch showing a cluster of microsporangiate strobili.

3. Make **drawings,** two or three times natural size, of a single young megasporangiate strobilus and a single microsporangiate strobilus.

4. Split both staminate and carpellate strobili lengthwise through the middle with a sharp razor blade and then make a **drawing** of the cut surface of each, on a large scale.

5. Remove a single entire megasporophyll from a young strobilus and, with the lens, find the two megasporangia on the upper side near the base. On the lower side will be found the bract. Make **drawings** on a large scale of the dorsal and ventral views of the megasporophyll.

6. Examine a single microsporophyll with the dissecting microscope and make large-scale **drawings** of two views which show clearly the form of the sporophyll and of the two microsporangia.

7. Mount and examine, under h. p. and l. p. of the compound microscope, fresh microspores, and make several **drawings** of these on a large scale. From prepared slides, **draw** several stages in the germination of the microspores.

8. **Draw,** at least natural size, a cone (mature megasporangiate strobilus).

9. **Draw** several seeds (megasporangia containing endosperm or female gametophyte tissue and embryo sporophyte) with their wings attached.

10. Carefully crack the seed coat of a large pine seed and cut the endosperm and embryo longitudinally through the middle. Then **draw** the resulting section on a large scale. The drawing should show the seed coat, the brown papery remnant of the nucellus, the female gametophyte tissue or endosperm, and the embryo with its numerous cotyledons, stem growing point, and radicle.

11. Using a local flora, determine the genus and species of the gymnosperms of which material will be furnished you.

Angiosperms

12. Make a **drawing,** at least four times natural size, of a single microsporophyll (stamen).

13. From prepared slides, make **drawings** on a large scale (l. p.) of a cross section of a mature anther (four microsporangia) of *Lilium* before dehiscence and of an anther after dehiscence.

14. Examine the sections of anthers after dehiscence with h. p., and find sections of microspores (pollen grains) which have begun to germinate and which show the **generative nucleus** and the **tube nucleus** of the young male gametophyte. **Draw** one of these on a large scale.

15. Make **drawings** of fresh pollen and of pollen which has formed pollen tubes in sugar solution.

16. Remove the pistil from a flower of *Lilium* and **draw** it at least four times natural size. Then cut a cross section of the ovary and **draw** this as seen under the dissecting microscope.

17. Using stained sections of *Lilium* ovary, **draw** a single ovule showing the funiculus, inner and outer integuments, **micropyle,** and nucellus with female gametophyte (embryo sac). No cell walls need be shown in this drawing.

18. From prepared slides, **draw** a section of a megasporangium showing four megaspores.

19. From the stained sections of *Lilium* ovary, **draw** 2-nucleate and 4-nucleate female gametophytes as seen under h. p.

QUESTIONS

Which of the classes of the Spermatophyta has the greater number of representatives on the earth to-day? Is the same true of both the number of species and of individuals? How would you distinguish between a spore and a seed? Contrast the position in which the seeds are borne on the megasporophylls of gymnosperms and of angiosperms. Are there any herbaceous gymnosperms? What members of the gymnosperms are most closely related to the pteridophytes? Give reasons for your answer.

Are the microspores and megaspores of *Pinus* borne on the same or on separate strobili? How many microsporangia on a single microsporophyll? Are the megaspores of *Pinus* formed

in tetrads as they are in *Selaginella*? Is the gametophyte of the pine independent or dependent? Are the microspores or the megaspores produced in the greater numbers in pine? Can you suggest how this might be an advantage to the plant? In what way are the wings of the pine pollen of aid to the plant? Can the expressions "seed plants" and "flowering plants," be used interchangeably? Give reasons for your answer. Are motile sperms known in the gymnosperms? About what is the average length of life of the gametophyte plants in the genus *Pinus*? How many cotyledons in the embryo of a pine seed?

What special names are given, in the flowers of angiosperms, to the following structures: microsporophyll, megasporophyll, microsporangium, megasporangium, microspore, and female gametophyte? Compare, as to the number of cells, the male gametophyte of a gymnosperm and of an angiosperm. What cells are found in the male gametophyte of a gymnosperm that are not found in that of an angiosperm? Name the nuclei of the female gametophyte of an angiosperm. What is double fertilization? In what plants is it found? Compare, as to origin and the time of development, the endosperm of a pine seed and of a wheat seed. Compare as to function. What are the essential parts of an angiosperm flower? Why? How do you account for the fact that the chances for pollination of most angiosperms is equal to that of gymnosperms, although the proportionate amount of pollen produced is very small. What is meant by monœcious? Dicœcious? Which is the more common condition in angiosperms?

Practice in the Determination of Some of the Commoner Genera and Species of Seed-bearing Plants

At some period during the semester, a study should be made of the commoner flowering plants of the vicinity. For this work a flora of the region will be used. The titles of the principal floras suitable for this work will be found on p. xvii.

APPENDIX

Permanent Preparations for Microscopic Study.—Though it is certainly desirable, in as far as it is possible to do so, to reduce the use of preserved material and permanent preparations to a minimum, some stained slides are practically indispensable. If it were not for the fact that most of the slides offered for sale are far from satisfactory, it would certainly be best to purchase whatever stained slides are needed. The authors have found it necessary to prepare, themselves, most of the slides used in this course. A few have been purchased, most of them from the New York Biological Supply Company, 34 Union Square, New York City. This company has undertaken to prepare sets of the various slides specifically called for in this guide. These slides are being prepared with the advice of the authors and according to their specifications and come nearer no doubt to their ideal of what such slides should be than do any now procurable.

The Cell.—It is suggested that students be directed to write in the laboratory or lecture room, and without reference while writing to any written notes or books, a rather extended account of the structures and activities of a typical green plant cell. This paper may well be announced at the beginning of the work on the cell, to be written just after the completion of that work. Material for such a paper may be taken from lectures, laboratory work, reading of the text (Holman and Robbins, Chapter II) and other sources. Students and assistants for the most part agree that the writing of such a paper is a most useful exercise. It tests the student's ability to recognize the most essential and significant facts and to properly organize these facts into a logical and well-balanced account. Specifying that nothing but "mental notes" are to be used assures some facts at least being actually learned by the students, and also reduces a great deal the likelihood that the students will merely reproduce verbatim, or paraphrase, the words of some text or printed account which they have read,

as a considerable proportion of them do when they are assigned a paper to prepare outside of class. The value to the student of the exercise just suggested depends, of course, very largely upon the care with which the paper is corrected by the instructor. Each error in fact, choice of facts, organization of material, logic, and English should be clearly pointed out so that these errors may be avoided later by the student. If similar papers on the stem, root, leaf, etc., are assigned later, it will be found that in most cases relatively few criticisms will be necessary.

Under the most favorable conditions, good stem tips of pumpkin or squash seedling can not be secured in less than 3 or 4 weeks after planting.

Elodea, sometimes called *Philotria* or *Anacharis*, can be purchased from dealers in aquarium supplies. The small-leaved species are best for our purpose. If the plants are to be grown in the laboratory, pond or river water to which a little soil has been added will serve as a good culture medium. If the cultures of *Elodea* are left in a moderately warm place for several hours before they are to be used, active streaming of the protoplasm will be much more likely. It is said that very active streaming may be assured by placing the *Elodea* shoots in a weak solution of methyl (wood) alcohol for from six to twelve hours before they are to be studied.

Cross sections through the petals of pansies often show, among the papillate surface cells, not only some which owe their coloration to soluble pigments in the cell sap and others colored by chromoplasts, but still others in which two pigments, one in the chromoplasts and one in the cell sap, are present in the same cell.

If microscopes with oil-immersion objectives are available, it is most desirable that demonstrations of the principal stages in mitosis be set up in the laboratory, since, with the highest magnification of the microscope usually provided for the use of students in elementary laboratories, the details of the process can not be very satisfactorily observed.

A satisfactory osmoscope to demonstrate osmotic pressure can be made from a thistle tube and a piece of parchment paper or pig's bladder, or from a diffusion thimble (Schleicher and Schull's) procurable from any of the larger laboratory supply companies. If a thistle tube is used, one with a large-bore stem

should be chosen. The parchment paper should be thoroughly soaked in water before being stretched over the thistle tube. It should then be fastened in place by winding tightly with heavy thread and tying. Leaking will be less likely if the thistle tube and parchment paper membrane are dipped in alcohol and then allowed to dry and if the edge of the paper is then sealed down to the glass by means of melted sealing wax. Filling the osmoscope with sugar syrup or molasses will be much easier if the stem of the thistle tube is cut off to within 1 or 2 centimeters of the expanded end. After filling, the osmoscope may be attached by a short piece of rubber tubing to a long glass tube of small bore, and immersed in water. If a parchment paper diffusion thimble is used, it is only necessary to fill it with molasses or sugar syrup and attach a tube by means of a rubber stopper. This should be wired in place.

If molasses is used, the coloration of the water outside the osmometer will soon show that the parchment paper membrane is permeable to certain of the dissolved substances within. Adding equal percentages of copper sulphate and potassium ferrocyanide respectively to the liquid outside and inside the osmoscope will make the membrane much less permeable to dissolved substances.

When using barium hydroxide solution (baryta water) or lime water to demonstrate the formation of carbon dioxide, it is often difficult to get the solution filtered clear. Filtering through several layers of ordinary filter paper or using a hard filter paper will generally do away with this difficulty.

The Tissues.—For directions for staining cross and longitudinal sections of woody stems or other plant material, consult either Stevens' "Plant Anatomy," or Chamberlain's "Methods in Plant Histology," published by the University of Chicago Press. Safranin and Delafield's haematoxylin make an excellent stain combination for sections of stems and roots. When these two stains are properly used, cellulose walls and the cell contents stain deep blue; and lignified, suberized, and cutinized structures, red or pink.

The instructor should make certain in advance that the matches to be used in Exercise 5 under "Directions for Work" are of coniferous wood, since many matches now on the market are of dicotyledonous wood.

The Stem.—Several of the demonstrations call for water-tight connections between a stem and a glass tube. A very satisfactory way in which to make such a connection is as follows: Choose a glass tube considerably larger in inside diameter than the stem which is to be used. Then procure a rubber stopper *slightly* smaller than the glass tube, and, with a cork borer considerably smaller in diameter than the stem, make a clean-cut hole in the stopper. The stopper and cork borer should be kept wet while boring the hole. Do not remove the borer from the stopper at once, but take the next larger cork borer, wet it thoroughly, and pass it over the cutting end of the first borer, so that the rubber stopper is transferred from the smaller to the larger borer. This operation should then be repeated, a larger borer being used each time until the hole in the stopper is sufficiently stretched to permit the stem to pass freely into the borer. Then it will be possible to push the stopper off from the cork borer on to the stem, and a water-tight connection will result. It is, of course, necessary that the large end of the stopper be at the free end of the largest cork borer used. The stem with stopper attached can now be pushed into the glass tube.

In the preparation of the demonstration of transpiration pull, considerable care will have to be taken in order to prevent any air being left at the top of the tube. The leafy shoot with rubber stopper should be thrust into a large tube which has been drawn out at the lower end and attached, by means of a short piece of rubber tubing, to a small-bore tube about a meter in length. Filling the two tubes with water and connecting the shoot, without permitting any air to enter the tubes, can most easily be done by having an assistant hold the lower end of the narrow-bore tube, just underneath the surface of the mercury, and almost close it with the finger while boiled and cooled water is poured into the large tube. After all the air has been driven out of the tubes, the assistant should close the lower end of the tube until the water overflows at the upper end. Then, with a little care, the stem and stopper can be fixed in place without any air being left in the tube.

The Root.—In order to obtain good root hairs for study, the containers (Petri dishes or terra cotta saucers are best) in which the radish and wheat seeds are to be germinated should be sterilized by steam or dry air sterilization or by boiling. In some

cases it may be necessary to sterilize the seeds also. This may be done by immersing them for fifteen minutes to half an hour in a 1 : 500 formalin solution and then washing in several changes of sterile water. The seeds can best be handled during sterilization and washing in cheese-cloth bags. Sterile forceps should be used to transfer these bags. In the containers, pads of sterilized filter paper moistened with sterile water should be placed, and the seeds allowed to germinate on these. A moderate temperature should be maintained during germination. Under the most favorable conditions three to four days will be required for the development of good root hairs in the case of radish, and from four to five days for satisfactory wheat seedlings.

It is clear that, in the demonstration of root pressure, the height to which the water rises may depend upon the bore of the glass tubing used. If a very large-bore tubing is used, the height of the column may give no idea of the pressure involved, for the liquid given out may not be sufficient to fill such a tube to the full height which the root pressure could support.

The Leaf.—Though it is quite easy to make relatively thick sections of leaves, which will serve for Exercise 6, under "Directions for Work," it is difficult to get good thin cross sections, such as are necessary if a satisfactory study of the detail structure of the leaf is to be made (Exercise 7). Sometimes fair free-hand sections can be secured by placing several strips of leaf between pith, or by cutting wide strips and making these into a tight roll wrapped at one end with thread or a rubber band. Sections made thus are generally not thin enough, or only thin enough in spots. Excellent thin sections, frequently extending across the entire width of the leaf and as thin as 15 micromillimeters, can be secured by means of the freezing microtome. (See Holman: Use of the carbon dioxide freezing attachment on the rotary microtome. *Science*, 57: 363–364. 1923.)

In order to compute the average loss by transpiration per square centimeter of leaf surface, it is only necessary to divide the total loss in weight by the total leaf surface. The total leaf surface can best be obtained by removing the leaves, tracing the outline of each on paper of relatively uniform thickness, and cutting out the tracings. If these tracings are then weighed and their weight divided by the weight of one square centimeter, secured by weighing a piece of the same paper having a known area,

the combined area of all the leaves can be determined. It should be borne in mind that each leaf has two sides of equal area, from which transpiration takes place.

For the demonstration, by the method of starch photographs, of the necessity of light for starch formation, various leaves may be used. It is not necessary that a rooted plant be used; leafy branches with stems in water are satisfactory. Natural illumination is not necessary. A hundred-watt or stronger electric bulb will give good results. If an electric light is used, it will be necessary to have it only a little distance from the leaf, and then some provision for keeping the leaf cool will be necessary. Very successful results have been secured by the use of a glass cooling chamber through which water is allowed to flow continuously. The light bulb may be placed against one side of the cooling chamber, and the leaf, with a mask of tinfoil or black paper between it and the glass, may be attached to the other wall by means of strips of paper.

Almost any green leaf will yield a good raw chlorophyll solution. Nettle (*Urtica*) was used in Willstaeter's famous researches on the four pigments present in raw chlorophyll solution. Ganong mentions, among other plants, the following as giving good chlorophyll solutions when the clear green, half-matured leaves are used: string beans, *Abutilon*, squash, most grasses, and *Tropœolum* (garden nasturtium).

A direct-vision spectroscope, preferably one with a comparison prism, which makes possible the examination, side by side and simultaneously, of the spectrum of light which has passed through chlorophyll, and that of light which has not, should be in every botanical laboratory. The price is not prohibitive. Spectroscopes of this type are listed in most of the laboratory supply catalogues.

The Flower.—*Sedum acre, Crassula quadrifolia* and certain other species of these genera are excellent for the first study of the flower, since they closely approach a pattern flower in the number and arrangement of the parts. If a greenhouse is available such flowers can be grown there, as well as *Linum* and a sufficient variety of other forms to supply material for all the exercises on the flower.

If material is securable it will be desirable to demonstrate to the class the movements of certain flower parts in response to

contact stimulus (thigmonasty). The cleft stigmas of *Mimulus* and *Diplacus* close, and the stamens of *Berberis* and *Mahonia* bend inward toward the pistil, when thus stimulated. The stamens of *Centaurea* and several other Compositæ are also sensitive to contact.

The Fruit.—Material of (*Prunus*), peach, plum, or apricot, should be collected when the stone is well formed but just before the stone becomes too hard to be easily cut with a knife. The material can be preserved indefinitely in a 4 per cent formalin solution. Just before it is to be used, it should be washed for half an hour in running water so that the formalin will not irritate the eyes and mucous membranes.

Material of *Lycopersicum* (tomato) should have the calyx still attached, and will be better if not quite ripe. If fresh material can not be secured when needed, fruits preserved in 4 per cent formalin will prove satisfactory, especially if they are collected while still quite immature and firm. The small yellow variety, sometimes known as *plum tomatoes*, are very much more desirable than ordinary tomatoes.

The Seed.—The seeds that are to be dissected should be soaked for twelve hours or more before being used.

The seeds of the smallest-seeded varieties of *Ricinus communis* (castor oil plant) though now somewhat difficult to secure in some localities, are much superior for dissection to the large-seeded variety now widely sold. In the latter the cotyledons of the embryo are often much wrinkled and folded so that it is very difficult to make a good dissection.

After twelve hours' soaking and at about 20° C., and with other conditions favorable, it will be necessary to allow the seeds to germinate at least for the periods given below, in order to secure the stages necessary to illustrate the progress of germination:

	1st Stage	2nd Stage	3rd Stage
Corn.....	36 hours	3 days	5 days
Lima Beans.....	36 hours	5 days	10 days
Castor Oil Seed...	4 days	1 week	2 weeks

The Algae.—Without very special care it is difficult to keep most of the filamentous algæ in culture for any length of time in the laboratory. Cultures of green algæ, kept around the labora-

tory in a moderately illuminated and cool place, often furnish, over a long period, material of certain Cyanophyceæ, *Scenedesmus*, diatoms, and various unicellular algæ.

During certain months of the year, the Botanical Supply Department of the Marine Biological Laboratory, Woods Hole, Mass., will furnish on order living material of *Fucus vesiculosus* to institutions in the East and the Middle West. Since this species is dicœcious and since the male and female plants are packed separately by the Woods Hole Laboratory, it is quite frequently possible to demonstrate fertilization by bringing together on a slide a quantity of the mucilaginous material from a female fruiting branch with some from a fruiting branch of a male plant.

Teachers on the Pacific Coast may be able to get material of *Fucus* by addressing the Hopkins Seaside Laboratory, Pacific Grove, California, or the Marine Biological Laboratory, Friday Harbor, Washington.

Preserved material of *Polysiphonia* (in alcohol or formalin solution) serves almost as well as fresh material and can be secured from various biological supply companies.

The Fungi.—Cultures of *Saprolegnia* can easily be secured by placing dead flies or wasps in jars of brook water or in algal cultures. After two or three days, the insect bodies should be placed in covered dishes of sterilized (boiled and cooled) water. When *Saprolegnia* is present, hyphæ will usually be seen growing out from the bodies of the insects by the end of the third day, and will soon completely envelop the bodies. Zoospores of *Saprolegnia* can usually be secured without difficulty if cultures containing sporangia are placed in a refrigerator and are then brought into the laboratory from one to two hours before they are to be studied.

Material of *Rhizopus nigricans* with abundant sporangia can be secured by growing the fungus on moist bread for about three days, at 23° to 25° C. Zygospores are generally formed profusely in bread cultures inoculated with the two strains and grown for twelve to fourteen days at 23° to 26° or somewhat longer at ordinary room temperatures.

If material is available, smut masses from smut-infected corn (*Zea mays*) should be displayed to the class.

Many interesting statements and experiments relative to the

sporophores of gill fungi, such as estimates of number of spores in single fruiting bodies of different species, their rate and method of discharge and dispersal, will be found in Buller's two volumes entitled "Researches on Fungi" and cited in the list of books for reference and collateral reading at the beginning of the Guide.

Bryophytes.—*Marchantia* often does well in flats in moist, rather cool and shady places in the greenhouse. *Lunularia*, a closely related form, grows abundantly in many greenhouses. It seldom reproduces sexually, but very commonly produces gemmæ cups, which, though crescent-shaped and thus quite different in form from those of *Marchantia*, will serve very well if gemma-bearing plants of *Marchantia* are not available. If fresh (living) material of *Marchantia* is not securable, the *Lunularia* will do for a study of the structure of the thallus of such a liverwort as *Marchantia*.

Sometimes it is difficult to secure enough moss protonema growing naturally outdoors to supply a whole class. Fortunately, moss protonema can be grown from spores by crushing capsules of *Funaria* or other moss on a piece of paper, from which the spores are then sown on the surface of earth in pots, either by gently blowing them or by inverting the paper over the pots of soil and tapping the paper. The pots should then be placed in saucers, covered with glass disks, and kept well watered but not too wet. Watering should be done by placing water in the saucer and not by watering from above. Early stages of spore germination and protonema formation may be secured by dusting spores on the surface of brook water or a dilute mineral nutrient solution.

Pteridophytes.—Similarly, young fern sporelings and very early stages in the development of the prothallia of ferns can be secured by sowing spores of *Onoclea*, *Polypodium*, *Aspidium*, *Pteris*, or other ferns, on the surface of a weak mineral nutrient solution. Fern prothallia can be grown to maturity by sowing the spores on earth in little pots or on rotting wood, as directed above for moss spores. Watering should be from below except when it is desired to secure sporophytes. Then the prothallia should be flooded to permit fertilization of the archegonia to take place.

Although it is very desirable that the material used for practice in the determination of ferns should be fresh material, dried specimens if collected at the proper time and well pressed may be

easily determined. In localities or at seasons when living ferns in fruiting condition are difficult to secure such dried material may prove useful.

Several species of *Selaginella* are commonly used as border plants or as space fillers in greenhouses under the benches. These often furnish excellent material for study.

Spermatophytes.—Seeds of large-seeded species of *Pinus*, such as those of *Pinus edulis*, *monophylla*, and *sabiniana*, are the best for dissection of the embryo.

Most pollens germinate in a wide range of sugar concentrations, but some are "more particular." An abundant supply of air is generally a condition of good germination and active growth of the pollen tubes. On this account, culture in hanging drops is most likely to be successful. An excellent procedure is to place large drops of the culture solution on the under side of a Petri cover and, after a ripe anther or two has been touched to each drop, to place the cover over a Petri dish containing a piece of wet filter paper. If one is doubtful as to the best concentration of sugar, one can place drops of different concentrations (beginning with 15 per cent and reducing by dilution to 10, 5 and $2\frac{1}{2}$ per cent) on one Petri dish cover, noting with glass pencil on the cover the concentration of the various drops. Among many flowers the pollen of which generally germinates freely, are *Eschscholtzia* (California poppy), *Tropæolum* (garden nasturtium), *Tulipa*, many species of *Lilium* and *Lathyrus odoratus* (sweet pea).

GLOSSARY

A

Achene, see page 41.

Adnation, see page 34.

Æcidium, a cup-shaped sorus characteristic of one stage of certain rusts.

Æcidiospore, one of the non-sexual spores which are developed in chains in the æcidium.

Aggregate fruit, see page 42.

Alternation of generations, the alternation of an asexual phase (sporophyte) with a sexual phase (gametophyte). The cells of the sporophyte have twice as many chromosomes as those of the gametophyte.

Androœcium, the stamens of a flower taken collectively.

Androsporangium, the sporangium within which androspores are produced.

Androspore, one of the small zoospores from which the dwarf male develops, in some species of *Œdogonium.*

Angiosperms, flowering plants, or plants which bear their seeds in closed receptacles.

Annual ring, the ring of tissue produced by a plant in one year, particularly applied to the wood.

Annular vessel, a trachea, the thickenings of which are in the form of rings.

Annulus, the thick-walled cells extending from the stalk over the sporangium and part way down the other side in many ferns. A ring of tissue on the stipe of a mushroom.

Anther, the enlarged upper portion of the stamen, which bears the pollen.

Antheridium, a male gametangium or sperm-producing organ.

Apothecium, an open or cup-shaped ascocarp or fruiting body of certain ascomycetes.

Archegonium, the multicellular egg-bearing structure found in bryophytes, pteridophytes, and in some spermatophytes.

Ascocarp, a structure in which asci are borne.

Ascospore, the spore produced in the ascus of the Ascomycetes.

Ascus, the sac-like sporangium characteristic of the Ascomycetes.

Auricles, two appendages occurring at base of the leaf blade in many grasses.

Auxiliary cells, cells with which the carpogonial filament fuses after fertilization in the red algæ.

Axil, the acute angle between a leaf and the stem from which it arises.

B

Basidiospore, the asexual non-motile spore produced on a basidium in the Basidiomycetes.

Basidium, the spore-bearing structure in the Basidiomycetes. It is usually club-shaped, 1 or 4 celled, and bears the spores upon protuberances called sterigmata.

Bast fibers, see page 11.

Berry, see page 40.

Bordered pits, thin regions in the walls of tracheids and tracheal tubes in which the cellulose wall on either side of the pit overarches the pit proper.

Bract, a modified leaf which subtends a flower or flower cluster.

Bud, see page 18.

Terminal bud, a bud at the apex of a stem.

Lateral bud, a bud elsewhere on a stem than at the apex.

Axillary bud, a lateral bud produced in the axil of a leaf.

Adventitious bud, a bud arising anywhere except at the stem apex in the leaf-axils. Adventitious buds may arise from stems, from roots in some plants, and rarely from leaves.

C

Calyptra, the old venter of the archegonium in many liverworts, mosses, and ferns, which enlarges as the sporophyte develops and continues to envelop part of the sporophyte for some time; particularly conspicuous in mosses.

Calyx, see page 33.

Cambium, meristematic tissue which, by its division, continues the growth in thickness of the stem or root.

Capsule, see page 41.

Carpel, a simple pistil or one of the members of a compound pistil, probably evolved from a leaf. A megasporophyll.

Carpellate strobili, made up of megasporophylls or carpels.

Carpogonium, the female gametangium of a red alga.

Carpospores, spores formed in the red algæ as a result of the growth and division of the zygote.

Caruncle, an excrescence found at the hilum in certain seeds.

Caryopsis, see page 41.

Cell, one of the structural units of which plants and animals are composed. Any cavity or space, as the cell of an ovary.

Cell sap, watery fluid contained within the vacuoles of plant cells.

Chlorophyll, the green pigment which is active in photosynthesis.

Chloroplast, a plastid containing chlorophyll.

Choripetalous, having all the petals separate.

Chromatin, the substance in plants, usually found in the nucleus, which bears the hereditary characters.

Chromoplasts, colored plastids not containing chlorophyll.

Chromosome, one of the chromatin aggregates found in the nucleus at the time of mitosis.

Cilia, a hair-like extension of protoplasm, by the movements of which zoospores, gametes, and many unicellular organisms can move from place to place.

Coalescence, see page 31.

Cœnocyte, a plant or plant part made up of cytoplasm containing many nuclei not separated by walls.

Coleoptile, see page 45.

Coleorhiza, see page 45.

Collenchyma, mechanical tissue in which the cell walls are much thickened at their corners.

Columella, the sterile axile structure within a sporangium.

Companion cells, small nucleated cells associated with the sieve tubes in the phloem.

Compound leaf, a leaf made up of a number of divisions or leaflets.

Conceptacles, cavities in which the gametangia are borne in certain brown algæ.

Conidiophore, one of the erect, spore-bearing branches found in many fungi.

Conidiospore, an asexual spore cut off from the end of a conidiophore.

Conjugation, the union of two similar gametes.

Cork, the protective tissue which displaces the epidermis of older stems and roots.

Cortex, primary, the region in stem or root between the epidermis and the pericycle; **secondary,** tissue lying within the phellogen and produced by the phellogen.

Corolla, the petals taken collectively.

Cotyledons, leaves arising from the basal node of the embryo in a seed plant, generally adapted for food storage, food absorption, or other special function.

Cuticle, the outer layer of the outer wall of the epidermis, consisting largely of cutin.

Cutin, a waxy, waterproof material of which the outer part of the outer wall of the epidermis is largely composed.

Cystocarp, see page 57.

Cytoplasm, protoplasm exclusive of the nucleus.

D

Dehiscent, opening at maturity (said of a capsule or anther).

Dentate, provided with teeth pointing outward, not forward.

Dichotomous, characterized by branching in which each branch divides into two branches of the same rank.

Dicotyledons, plants in which the fibrovascular bundles are in a ring and the seed leaves are commonly two.

Diffusion, the tendency for the particles of two mutually soluble substances to become uniformly distributed throughout a solution.

Dimorphous, having two different forms.

Disk-flower, see page 38.

Dissemination, the scattering of seed, pollen, spores, etc.

Distinct, like parts not united.

Dorsal, referring to the back.

Drupe, see page 41.

Dwarf males, the small male plants of certain *Œdogonium* species, which grow epiphytically on the female filament of the same species.

E

Egg, a female gamete.

Embryo, a rudimentary sporophyte plant. In the flowering plants the term is not used after the germination of the seed has taken place.

Embryo-sac, the female gametophyte of spermatophytes.

Endocarp, the inner layer of the pericarp, or fruit wall.

Endodermis, the innermost layer of the cortex of a stem or root, often called the starch sheath.

Endosperm, the nutritive tissue found in seeds outside the embryo.

Endospores, the thick-walled spores formed within cells of some kinds of bacteria.

Enzymes, non-living organic substances produced by living organisms, and able to accelerate the rate of certain chemical changes without undergoing any chemical change themselves.

Epidermis, the outer cell layer (rarely more than one) of most plants above the Thallophyta.

Exocarp, the outer layer of the pericarp, or fruit coat.

F

Fascicular, pertaining to the vascular bundle.

Fertilization, the union of two unlike gametes.

Fission, multiplication by simple cell division into two equal cells.

Floret, see page 38.

Follicle, see page 41.

Foot, that portion of the sporophyte which attaches it to the gametophyte and which absorbs materials from the gametophyte.

Free, unlike parts not united.
Frond, the leaf of a fern.
Fruit, see page 40.
Fucoxanthin, see page 55.

G

Gametangium, the organ which produces gametes.
Gamete, a sex cell.
Gametophyte, the gamete-bearing plant.
Germination, development of a spore into a plant; also, in the seed plants, the resumption of development by the embryo after a quiescent period.
Gill, one of the hymenium covered plates of the Agaricaceæ.
Glumes, the two outer bracts which enclose each spikelet in grasses.
Guard cells, the two cells which surround the stomatal opening.
Gymnosperm, a spermatophyte in which the seeds are borne in open receptacles.
Gynæcium, all of the carpels of a flower as a unit.

H

Herbaceous, having the character of an herb, that is, a flowering plant that is not woody.
Hesperidium, see page 41.
Heterocyst, a large colorless cell occurring in the filaments of some blue-green algæ.
Heterogamous, producing two kinds of gametes.
Heterophyte, a plant which is not able to manufacture its own food.
Heterosporous, bearing two kinds of asexual spores.
Holdfast, a differentiated basal structure consisting of one or more cells, by which certain algæ are attached to the substratum.
Hormogonia, the short filaments of cells into which certain blue-green algæ may break up.
Hymenium, the spore-bearing layer (of asci or basidia) in certain fungi.
Hypha, one of the strands, or filaments, which make up the mycelium as well as the reproductive structures of most fungi.
Hypocotyl, the portion of the axis of the embryo seedling between the attachment of the cotyledons and the radicle.
Hypodermis, a term sometimes applied to the tissue just beneath the epidermis.

I

Indehiscent, not opening at maturity.
Indusium, the covering of the sori in many species of ferns.
Inferior ovary, an ovary to which the other flower parts appear to be attached.

Inflorescence, a flower cluster.
Integument, the layer or layers of tissue which enclose the embryo-sac and nucellus.
Intercellular, between the cells.
Interfascicular, between the vascular bundles.
Internode, a region of the stem between two nodes.
Intracellular, within the cells.
Intrafascicular, within the vascular bundles.
Involucre, a whorl of bracts subtending a flower or flower cluster.
Isodiametric, having approximately the same diameter in all directions.
Isogamous, producing similar gametes.

K

Keel, see page 36.

L

Lateral conjugation, the conjugation of adjacent cells in a filament, as in *Spirogyra.*
Leaf scar, the scar left on the stem after the leaf has fallen.
Legume, see page 41.
Lemma, the outer one of the two bracts inclosing a grass flower.
Lignin, a constituent of the ligno-celluloses which are abundant in the walls of tracheal tubes, tracheids and the bast fibers of many plants. Such tissues a e said to be lignified.
Ligulate, furnished with a ligule.
Ligule, a strap-shaped organ.
Linear, long and narrow, with parallel margins.
Linin, the net-work within a nucleus upon which the chromatin granules are found.
Lodicule, one of the scales within the flower of certain grasses.
Lunate, crescent-shaped.

M

Median optical view, a view halfway between the upper and lower surface of a structure.
Medulla, the pith of a stem. The inner region of the thallus in certain brown algæ.
Medullary ray, the parenchymatous tissue between the vascular bundles in stems and old roots.
Megaspore: Certain of the pteridophytes and all the seed-bearing plants produce two kinds of spores, megaspores and microspores. These differ in size in the lower forms, the former being much the larger. In all cases the microspore upon growth gives rise to the male gametophyte, the megaspore to the female gametophyte.

Megasporophyll, the leaf bearing the megasporangium or megaspore-containing organ.

Meristem, a tissue in which the primary function of the cells is to give rise to new cells.

Mesocarp, the central region of the pericarp, or fruit wall.

Mesophyll, the parenchymatous tissue of a leaf.

Microspore, see megaspore.

Microsporophyll, the leaf bearing the microsporangium or microspore-containing organ.

Middle lamella, the original thin wall separating two adjacent cells.

Mid-rib, the central or main vein of a leaf.

Mitosis, indirect cell division.

Molecule, see page 4.

Monocotyledons, angiosperms in which the fibrovascular bundles are scattered throughout the stem, and in which there is but one seed leaf.

Morphology, that branch of a biological science which is concerned with the study of the structure of organisms.

Mycelium, see page 60.

N

Neck (of an archegonium), the upper slender portion of an archegonium through which the sperm must pass in order to reach the egg.

Net-veined, furnished with branching veins which form a net-work.

Nodes, those regions which alternate with the internodes of a stem and from which leaves and branches normally arise.

Nucellus, the layer or layers of cells in an ovule which surrounds the embryo-sac and lies within the integuments.

Nucleolus, a small globular body (often more than one) found within the nucleus.

Nucleus, the dense protoplasmic body within the cell which probably controls the activities of the cell.

Nut, see page 41.

O

Oogonium, the female gametangium bearing the egg in the Thallophyta.

Oospore, the product of the fusion of two unlike gametes.

Operculum, the lid at the top of the capsule of a moss.

Orbicular, circular.

Organ, a part of an organism specialized to perform one or more functions.

Osmoscope, an apparatus for the demonstration of osmosis.

Osmosis, the movement of a solvent through a membrane, from a solution with a smaller concentration of dissolved particles to one of greater.

Oval, roundish in outline, with the breadth more than half the length.

Ovary, the portion of the pistil containing the ovules.
Ovule, rudimentary seed; megasporangium (nucellus) with integuments.

P

Palea, see page 37.
Papilionaceous, a flower having a banner, wings, and a keel, especially typified by members of the Pea family.
Palisade parenchyma, one or more rows of the elongated parenchyma cells just beneath the epidermis of a leaf and arranged at right angles to it.
Palmate, radiating from a common point.
Panicle, an open, irregularly branching, compound flower cluster.
Papilla, short cellular protuberance.
Pappus, see page 38.
Parallel-veined, having venation in which all the veins are parallel. The cross veinlets are also parallel.
Paraphyses, the sterile hairs found in the fruiting bodies of many Thallophyta.
Parasite, an organism which obtains its food from another living organism.
Parenchyma, tissue composed of thin-walled, rather regularly shaped cells, found in many plant organs.
Pedicel, the stalk of a flower in a flower cluster.
Peduncle, the stalk of a flower cluster or of a solitary flower.
Peltate, shield-shaped. A leaf shape in which the petiole is attached within the margin of the leaf.
Pepo, see page 41.
Perfoliate, a type of leaf in which the stem runs through the leaf within its margin.
Perianth, the calyx and corolla of a flower taken collectively.
Pericycle, the tissue between the endodermis and the vascular tissue in a young stem or root.
Peristome, one or two rows of teeth around the opening of a moss capsule just beneath the operculum.
Perithecium, a closed ascocarp, or fruiting body, in which asci are found.
Petal, one of the members of the second whorl of a complete flower, often colored and showy.
Petiole, the stalk of a leaf.
Phellogen, cork cambium.
Phloem, that part of the vascular bundle of a plant which is made up of sieve tubes and companion cells and probably conducts food and water downwards.
Phycocyanin, see page 51.
Phycoerythrin, see page 57.

Physiology, that branch of a biological science which is concerned with the study of the functions of organisms.

Pileus, see page 68.

Pinna, one of the primary divisions of a compound leaf.

Pinnate, having the leaflets arranged along the sides of a main leaf axis (rachis).

Pistil, the seed-bearing organ of the flower, consisting of the ovary, stigma, and style when present.

Pith, the large-celled thin-walled parenchymatous tissue in the center of the stem.

Placenta, that portion of the ovary wall to which the ovules are attached.

Plasmolysis, the condition of a cell in which the cytoplasm has shrunk away from the cell wall, due to the withdrawal of water from the cell sap.

Plastid, a small cytoplasmic body which may secrete certain enzymes or pigments.

Plumule, the rudimentary terminal bud of the embryo in a seed.

Pod, see page 41.

Pollen, the microspores of seed plants.

Pome, see page 41.

Primordium, an organ in its youngest stages of development, in which all of the cells are alike.

Procarp, see page 57.

Prothallium, a gametophyte plant which is in the form of a flat thallus.

Protonema, the alga-like branched filaments developing from the spore in mosses. From branches of the protonema develop the leafy moss plants.

Protoplasm, the living material of plants and animals.

Protoplast, the protoplasm of a single cell.

R

Rachilla, see page 37.

Rachis, see page 37.

Radial longitudinal section, a longitudinal section which is cut parallel to the radius of a cylindrical organ.

Radicle, the root found in the embryo of a seed.

Raphides, see page 11.

Ray-flowers, see page 38.

Receptacle, see page 33.

Reniform, kidney-shaped.

Resin ducts, tubes containing or excreting resin.

Respiration, see page 8.

Rhizoids, filamentous structures, found in many gametophytes, which perform the functions of root hairs.

Rhizome, a slender, horizontal, underground stem.
Rhizophore, see page 79.
Ringed cells, the cells in *Œdogonium* which have the ability to divide.

S

Samara, see page 41.
Saprophyte, an organism deriving its food from the dead bodies of other plants or animals or their products.
Sclerenchyma, see page 19.
Scutellum, see page 45.
Seed, a matured ovule containing an embryo sporophyte.
Sepal, see page 33.
Serrate, provided with teeth which point forward.
Sessile, without a stalk (applied to leaves, flowers, and fruits).
Seta, see pages 73–75.
Sieve plates, perforated end walls of the sieve tubes.
Sieve tubes, elements of the phloem, consisting of elongated cells with oblique porous end walls. It is through these that the elaborated food is supposed to pass down in the stem.
Silique, see page 41.
Sinus, the cleft between two lobes.
Sorus, a term applied to a group of sporangia and to a group of spores in certain fungi.
Sperm, male gamete.
Spermagonium, a flask-shaped structure formed along with the æcidium of certain rusts, in which non-functional spores develop.
Spike, a flower cluster in which the flowers are sessile along the rachis.
Spikelet, see page 37.
Spiral tracheæ, tubes in which the thickening is continuous and passes around the cell spirally.
Spongy parenchyma, leaf tissue with conspicuous intercellular air spaces.
Sporangiophore, the stalk of a sporangium.
Sporangium, an organ in which asexual spores are produced.
Sporelings, young plants developing from spores.
Sporophore, a term used to designate the reproductive bodies in fleshy fungi.
Sporophyll, a leaf-like structure bearing sporangia.
Sporophyte, the asexual spore-producing phase or generation of bryophytes, pteridophytes, and spermatophytes.
Stamen, the microsporophyll of a seed-bearing plant.
Sterigma, one of the spore-bearing branches of a basidium.
Stigma, the portion of the pistil which receives the pollen.
Stipe, stalk.

Stipules, appendages on either side of the base of the leaves of many plants.

Stolon, a portion of the plant which is decumbent upon the ground and which gives rise to new shoots.

Stoma, one of the pores in the epidermis of leaves or young stems through which gas interchange is carried on.

Stone cells, lignified mechanical cells which are about the same diameter in every direction.

Strobilus, a specialized cone-like portion of the shoot upon which are found the sporophylls.

Style, see page 34.

Superior ovary, a term applied to an ovary from which the other flower parts are distinct.

Suspensor, an elongated structure characteristic of the young embryo of the Spermatophyta and of *Selaginella* and related plants.

Sympetalous, having all the petals united.

T

Tangential longitudinal section, a section of a fruit, stem, or root which is at right angles to a radius of the structure.

Tegmen, the inner seed coat.

Teleutospore, a thick-walled (sometimes several-celled) spore of rusts.

Testa, the outer seed coat.

Tetraspores, asexual spores produced in groups of four in most of the red algæ.

Thallus, plant body of the thallophytes, or the flattened gametophyte of bryophytes and pteridophytes.

Tracheæ and **Tracheal tubes.** Tubes in the xylem formed from the dissolution of the end walls of large dead cells. They serve for water conduction.

Tracheids, single elongated conducting cells of the xylem. They have pointed end walls and are usually thickened in some fashion.

Transfusion cells, thin-walled cells in the endodermis of the root.

Transpiration, loss of water in the form of vapor from living plants.

Trichogyne, the slender extension of the carpogonium through which the male gamete enters the carpogonium.

Tumid, swollen.

U

Uredospore, one-celled summer spore of the rusts.

V

Vacuole, a cavity in the protoplasm, filled with water and dissolved materials.

Venation, the manner in which the veins are distributed in the leaf of a plant.
Venter, the swollen part of the archegonium, which contains the egg cell.
Ventral, of or pertaining to the lower surface.

W

Wing, a membranous expansion on a seed or other part.
Wood, the central cylinder of a tree, inside the cambium ring.

Z

Zoospore, a motile asexual spore.
Zygospore, a zygote formed by the union of similar gametes.
Zygote, the cell resulting from the fusion of two gametes.

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